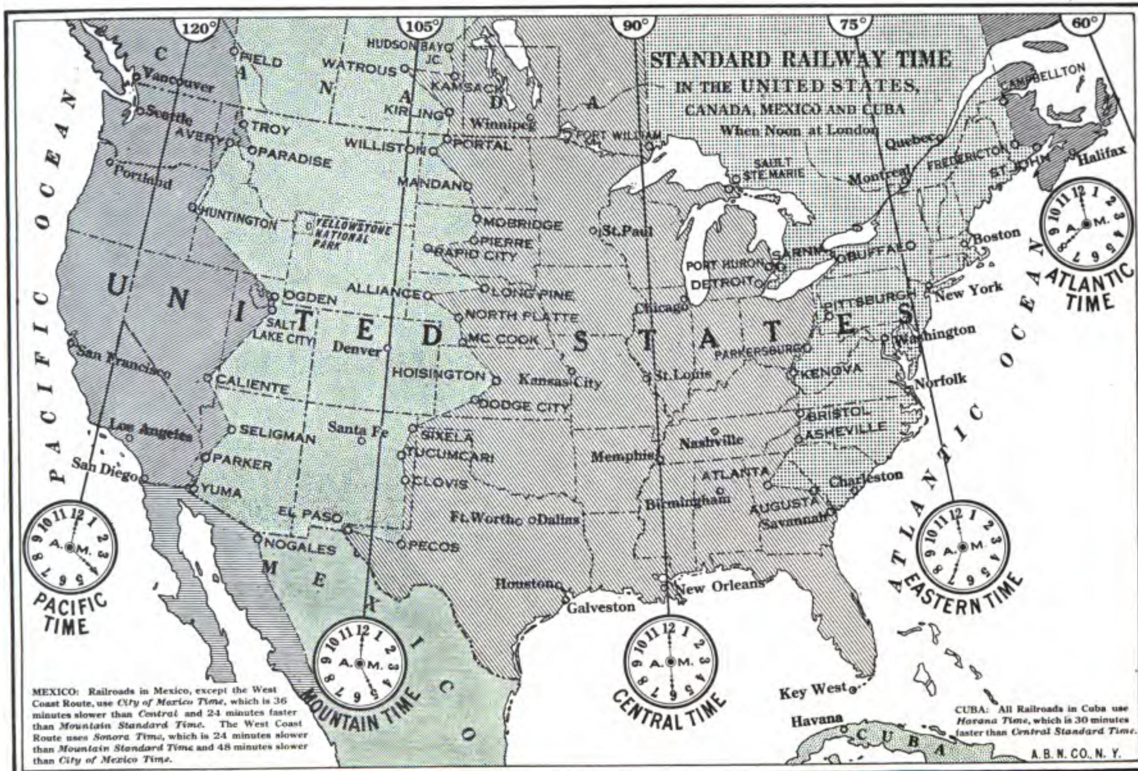

MEXICO: Railroads in Mexico, except the West Coast Route, use *City of Mexico Time*, which is 36 minutes slower than *Central* and 24 minutes faster than *Mountain Standard Time*. The West Coast Route uses *Sonora Time*, which is 24 minutes slower than *Mountain Standard Time* and 48 minutes slower than *City of Mexico Time*.

CUBA: All Railroads in Cuba use *Havana Time*, which is 30 minutes faster than *Central Standard Time*.

FIRST OBSERVATIONS
IN
ASTRONOMY

A HANDBOOK FOR SCHOOLS AND COLLEGES

BY

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CONCORD, N. H.
THE RUMFORD PRESS
1913

PREFACE

Real knowledge in science depends upon direct study of objects and phenomena. Astronomy is no exception. Literally to look up, to see with our own eyes and to find out by seeing,— these things are the beginnings of astronomy.

As a guide to first observations, this handbook has been written. With few exceptions, the mechanical appliances required can be made by a carpenter or by the students themselves. Simple tools are best at first. It needs but slight experience with protractors, plumb lines, gnomons, and sun-dials to realize how aptly they can be used in scientific training, and how much meaning they put into different subjects. Not a little light will reach some of the dark places of geography and arithmetic, when teachers are accustomed to make simple observations, and know how to interest boys and girls in finding the latitude of the school building with the window gnomon, and the error of the clock from the horizontal sun-dial. At present, we sometimes have so-called courses of nature study with the sun in heaven left out!

A few topics of advanced character, dealing mainly with time and longitude, have been included in the final chapter; but, as a rule, simplicity of treatment has been carefully guarded, and mathematical knowledge beyond elementary branches is not required.

No effort has been made to deal even in a cursory manner with descriptive astronomy. It must, of course, receive its due meed of attention, and when the sky is cloudy, or the weather very cold, emphasis is naturally placed on that part of the subject.

To add vividness to the illustrations, many observations have been prepared, under the writer's direction, in different parts of the country, by different students, and are marked with their initials.

Grateful acknowledgement is made to those who have read the book wholly or partly in manuscript and given help in other

ways, especially to Professor Harriet W. Bigelow of Smith College and Mary M. Hopkins, Instructor there, to Professor Anne S. Young of Mount Holyoke and Professor Ellen Hayes of Wellesley. Mention should also be made of Louise Barber, and Jane T. Vermilye, former assistants at Smith, who have contributed some of the more difficult observations, and to another Smith alumna, Lucy Stoddard, who has aided in preparing the index.

Professor William F. Rigge has kindly allowed the use of two diagrams, illustrating a solar eclipse, which accompanied an article of his in *Popular Astronomy*. In this permission the editor of the journal, Doctor Herbert C. Wilson, courteously joins, and also gives leave to make use here of articles by the writer which first appeared in the same journal.

Freedom of access to the library and the use of some of the astronomical instruments of the State University of Kansas are privileges that have been highly appreciated; and no small debt is owed to A. Marks, a jeweler of Lawrence, Kansas, whose kindness and courtesy in sending accurate time by telephone rendered it possible to test a home-made transit instrument, and to determine longitude from local observations.

References to descriptive astronomy are made to "Young's Elements of Astronomy," and are designated by "Young." Those to "Byrd" refer to the writer's "Laboratory Manual in Astronomy."

MARY E. BYRD.

NEW YORK, N. Y.
November, 1913.

CONTENTS.

INTRODUCTION.

1. Equipment.—The unaided eye is no mean astronomical instrument, and when the sky is clear, the main objects of astronomical study are ready at hand. There is, however, little value in haphazard star-gazing. A definite scheme of work, under competent instruction, should be carried on regularly, in the day-time and in the evening. Mechanical appliances at first may be few and simple, as for example:

1. Meridian stone and carpenter's level.
2. Altazimuth for measuring angles.
3. Plumb lines and sun-dial for finding time.
4. Gnomon for determining latitude and time.
5. Celestial globe and good watch or clock.
6. Opera-glasses or small telescope.*

This, in the main, is the equipment assumed in giving instructions for a large number of observations. Details regarding it are to be found in the first chapter, and there also other apparatus is described.

The suggestion may seem premature, but it is certain that a small building devoted to astronomy is an advantage in many ways. It affords the needed shelter for plumb lines, and gives opportunity for mounting permanently instruments like the sun-dial and home-made transit which must be critically adjusted in the meridian. A good view of the heavens should be insured from its roof, and if a section of that is removable, work with small telescopes is facilitated. Wear and tear is also saved by

*With the exception of a good time-piece and the celestial globe which many schools possess, the cost of these appliances will probably amount to about fifty dollars.

not carrying instruments from place to place, and efficiency and rapidity in observing, promoted.

2. **Fundamental observations.**—It has been the aim in the following chapters to present a large number of observations, extending over a somewhat wide range of topics, and including those that are short and simple, as well as those requiring not a little time and effort. From them, if desired, different groupings can be made, and courses adapted to varying needs and conditions. In any scheme, as far as practicable, place should be given to the essential observations along different lines. Thus, in all direct study of the heavens, five subjects stand out prominently:

1. The Constellations.
2. Diurnal Paths of Heavenly Bodies.
3. Paths of Sun, Moon, and Planets among the Stars.
4. Face Appearance of Sun and Moon.
5. Latitude and Time from Sun and Stars.

The following list of observations is suggested as giving due recognition to each of the above subjects, and providing a midway course for beginners, neither very easy nor very hard:

1. Become familiar with thirty-five constellations so as to recognize them readily in different seasons.

2. Make separate sketches of twenty constellations, directly from the sky, including at least seven stars in each.

3. Twice in the same evening, allowing an interval of an hour or more, note the position of three bright constellations, one chosen near the eastern horizon, one near the meridian, and the third near the horizon toward the west.

4. Orient four of the circumpolar constellations in reference to the North Star, twice in the same evening, allowing an interval of an hour or more.

5. Fix a diurnal path of the sun by finding its altitude and azimuth at five different times, including if possible southing and setting.

6. At intervals of three weeks or more, fix approximately five other diurnal paths of the sun, making several determinations of altitude and azimuth.

7. Fix a diurnal path of the moon by measuring its altitude and azimuth at five different times, including either rising, southing or setting.

8. Check meridian altitudes from declination, and azimuths at rising or setting from the celestial globe.

9. Plot all diurnal paths on rectangular paper and note the following points:

(1) Changes in noon altitude and sunset point.

(2) Connection between the extent of solar paths and seasons of the year.

(3) Likeness or unlikeness of solar and lunar paths.

(4) Connection between the extent of a path and declination of the body.

10. Note, two or three times, at an interval of a month or more, the zodiacal constellation first seen in the west after sunset.

11. Find out by observation how soon the moon is visible after new moon, where it is first seen, and in what direction the horns point.

12. Find when and where the moon rises on a night when it is full, both in the fall and in the spring.

13. A day or two before full moon, and a day or two after, note which limb is defective.

14. On five or more nights in one lunation, fix the moon's place by estimating its distance and angular direction from neighboring stars.

15. From the data of the preceding observation, find the moon's sidereal period, and its daily rate of motion.

16. From observations of the phase of the moon, made in two or three lunations, find the approximate length of its synodic period.

17. Map one of the bright planets among the stars, on ten evenings at intervals of a few days or a week or two, according to its rate of motion.

18. In like manner, map a second bright planet on five evenings.

19. From the data obtained by observations 17 and 18 plot the paths of the planets observed, on specially prepared star-maps, and note the following points:

(1) In what direction each planet is moving among the stars, and whether the direction of either changes.

(2) How rates of motion of one planet at different times, or both planets at the same time, compare.

(3) How the paths are placed with regard to the ecliptic, and what constellations are traversed in whole or in part.

20. Plot on the celestial globe the positions of a planet for two dates, and find its motion in right ascension and declination for the interval.

21. Locate a north and south line with the aid of a gnomon.

22. Observe the transit of the same star twice over the same reference line, so as to find out which is the longer, the sidereal or mean solar day, and by how many minutes the two differ.

23. At sun noon find the error of a watch within a minute,

(1) From the gnomon.

(2) From plumb lines used as a transit instrument.

24. At any hour of the day, find the error of a watch within a minute from the sun-dial.

25. Determine the latitude of the place of observation within half a degree,

(1) From the sun's altitude at noon.

(2) From the altitude of a star south of the zenith.

(3) From the altitude of the North Star, on or off the meridian.

26. Trace the celestial equator and ecliptic in the heavens by the stars near their paths, noting the position of the equinoxes.

27. Make two sketches five or six months apart, showing where the equator and ecliptic intersect the horizon.

28. Determine the magnifying power of an opera-glass, and test it for double field of view, double image, and fringes of light.

29. Examine ten objects with opera-glasses, including sun, planets, star clusters, nebulæ, and double stars.

30. Identify seven objects on the moon.

31. Determine the focal length, field of view, and magnifying power of a small telescope.

32. Examine with a telescope ten objects, including sun, planets, star clusters, nebulæ, and double stars.

33. Identify fifteen objects on the moon.

To carry through observations like these intelligently, and derive satisfactory results really requires more and means more than is easily realized by merely reading them over. One of the objects in writing the handbook has been to present in orderly sequence the precepts, explanations, and illustrative observations that are needed in actually doing the work which is here briefly indicated.

CHAPTER I.

PLACE FOR OBSERVING; HOME-MADE INSTRUMENTS; MISCELLANEOUS APPLIANCES; DEFINITIONS; DIRECTIONS FOR OBSERVING AND RECORDING.

3. **Observing station and laboratory.**—The first requisite for an observing station is a good view of the heavens. The horizon line on the south, and either on the west or east should be, as far as possible, unobstructed by trees and buildings. If there is no store-room near at hand, water-tight lockers should be provided, in order to protect instrumental appliances from the weather, when not in use.

There are advantages in an observing station on the ground; but, since the all-important thing is to see the sky, it may be necessary to provide for it on a flat roof. Wherever placed, it should open directly upon, or closely adjoin, one or more well-lighted rooms, for really efficient observing depends intimately upon work at the desk. This laboratory, if the term may be allowed, is the place for consulting almanacs, maps, and globes during observation, for making sketches, and writing the notes of the evening's work. Here, in the daytime, instruments are examined and tested, preparatory to their use, and the different operations carried on which are required in reducing and discussing observations.

4. **Meridian stone.**—When routine observing is done on the ground, set a flagstone, about three by five feet, where the best view of the celestial meridian is obtained (§ 15, *20*). Let it be carefully levelled, and rest on a sand foundation, a foot or two deep, that it may be, as little as possible, disturbed by the weather.

On the roof, a wooden platform somewhat larger takes the place of the stone. It should be painted and well braced to

prevent warping and shift in position, which would be likely to vitiate the level and displace the meridian line.

If, as often happens, it is desirable to accommodate more than one observer at the same time, there may be several stones or platforms with the meridian line (§ 6) marked on each.

5. Gnomon.—An upright shaft set firmly in place on a horizontal surface constitutes the common gnomon. Instead of the upright, the section of a sheltered plumb line may be employed (§ 43, Obs. 2), but neither shaft nor shadow is essential. Almost any window, facing in a southerly direction, can be utilized for a gnomon in which the sun's image takes the place of the shadow.

The essentials are few and simple. Let the lower sash contain a single, large pane of plate glass, and a projecting board be placed at right angles to it. The latter should be covered with white paper or cardboard, and a piece of dark paper with a small, nearly circular aperture pasted on the glass. The height of the gnomon is, then, the perpendicular from the center of the aperture to the projecting board, and the length of the "shadow" is the distance from the foot of this perpendicular to the center of the solar image which is formed on the board by light passing through the aperture (§ 31).

This solar-image gnomon is especially convenient in cold weather, and at all times the required measurements are made with marked accuracy and rapidity. It may be adapted, if desired, for use out of doors, by substituting for the upright post a straight edge having a long, narrow slot, and movable disk with a circular aperture.

6. Meridian line.—A meridian line is essential in using much of the simple apparatus required in elementary astronomy. It may be located approximately by the North Star, or from the shadow of a common gnomon (§ 61); but it is more accurately determined by an image of the sun (§ 5).

First, let a sheet of cardboard, on which arcs of concentric circles have been drawn, be fastened to the projecting board or

platform, where the meridian line is desired. The center of these arcs is to be taken as one point in the meridian, and to find a second, proceed somewhat as follows:

Suspend a plumb line, so that when the point of the bob comes to rest over this center, the line itself passes centrally across the aperture used. Then, rather more than an hour before apparent noon, begin to watch the solar image, and as it moves to the south, mark its center at the instants when it coincides successively with three or four of the concentric arcs. In like manner, after noon, fix points on the same arcs, as the image moves northward. In making all marks, the image itself should be the only guide, that is, no time-piece should be consulted.

Now, theoretically considered, if the sun's declination were constant during observation, the two points thus marked on any one arc ought to be equally distant from the meridian; and, so if the chord connecting them is bisected, a second point in the meridian is obtained. (See Dialling, Encyclopædia Britannica.) Notwithstanding the sun's motion, however, and the unavoidable errors in locating the center of the image, the mean position, derived from the bisection of several arcs should give quite accurate results. As a further precaution, it is well to repeat the operation on another date, and finally after the line has been drawn, it should be tested by actual observations.

7. **Meridian stand.**—If two posts, about five feet high, are set firmly in the ground on either side of the meridian, they provide a stable support for a shelf, making altogether a high stand for the use of jointed-rods (§ 11). The shelf should be removed easily, in order to leave an open space to the north and south whenever desired, and care must be taken to have it level and the direction of its sides true to the points of compass.

8. **Plumb lines.**—Two plumb lines may be employed in observing transits, by sighting so that they appear as one. Such lines are used mainly in finding time from the sun, and a few bright stars, and it is, therefore, essential that they should be placed

accurately in the plane of the meridian, and remain perfectly steady during observation. The problem of light also requires special consideration. The sun is so bright that when it is observed, a large part of its light must be cut off; and at night the lines must be illuminated, but without much diminishing the star's brightness. Electric lights, on account of the ease with which they are adjusted and controlled, are preferable, but small kerosene lanterns will do very well (§ 62, Obs. 2).

Fish tackle is good material for plumb lines, whether they are coarse or fine; and the thickness desired, as it depends largely upon the distance between the lines, the objects to be observed, and the method of lighting, is best found by experiment.

9. Plumb-line booth.—The three requisites for serviceable plumb lines, steadiness, proper lighting, and position in the meridian are most readily attained by placing the lines under shelter. A plumb-line booth, in order to accommodate two observers at the same time, and a larger number at different times, should have a floor space, at least eight by ten feet, and a height not less than six feet. The floor must be firm and level, and if it is painted white, the meridian line is more easily established and plainly marked.

Convenience and independence in observing are facilitated if the booth is divided into two compartments by a partition passed north and south through the center. Each part is then entered by a door on the north, and opposite, in the south wall are narrow openings, which are protected, when the booth is not in use, by wooden shutters. These can be made in two or three sections, and at night, if the upper one is left open, there is an unimpeded passageway for the star's light. On the other hand, for day work, this aperture may be covered with colored glass, dark enough for looking directly at the sun.

Plumb lines are conveniently hung from screw hooks in the ceiling. Locate first the two in the meridian, one near the middle of the south opening, and the other, two or three feet farther north. On either side of the latter, a little distance from it, east

and west, *i. e.*, in the prime vertical (§ 15, *9*), suspend two other lines. Thus, three sets of reference lines are obtained; for by sighting, each north line is made to coincide with the one at the south. If there has been good success in placing these lines accurately, they constitute no mean form of transit instrument; for the final determination of time is made to depend upon several transits, independently noted (§ 62, Obs. 1, 2).

To provide for off-meridian transits by different observers, several additional lines may be placed in the prime vertical just mentioned, each pair being distinguished by some such designation as, "south line and that from screw hook No. 5." Equipped in this manner, the two compartments give opportunity for noting ten or more transits of the same star in the same evening, facilities that are especially convenient for a large number in finding the length of the sidereal day (§ 63).

10. Home-made transit instruments.—A home-made telescope (Byrd, Appendix), or any small telescope, mounted in the meridian, is serviceable as a transit instrument. It should be given a heavy wooden support consisting of a base and two uprights (Fig. 1). The telescope tube ought to be fitted permanently into the horizontal axis, and the ends of the latter, which rest in the wyes of the uprights, should be as nearly as possible circular in form and equal in diameter. The whole frame can be fixed in position on a meridian platform by stationary blocks, placed one at each corner, and if they are pierced by coarse screws, they give means for adjusting in azimuth (§ 85).

One way to light the field of view is to hang a small lantern on a movable upright, placed to one side, a little distance from the object-glass. This upright may be passed through a block on a stand, and provided with a set screw, so as to be clamped at different altitudes as the telescope is moved up and down. The lantern, so nearly in the line of sight, must be carefully adjusted and hooded that it may not inconvenience the observer.

The striding level employed with the instrument is shown in position in Fig. 1. It is made by mounting a level tube, like

that of a carpenter's level, in the middle of a "turned" axis, having about the same diameter as that of the horizontal axis on which the wyes of its legs rest.

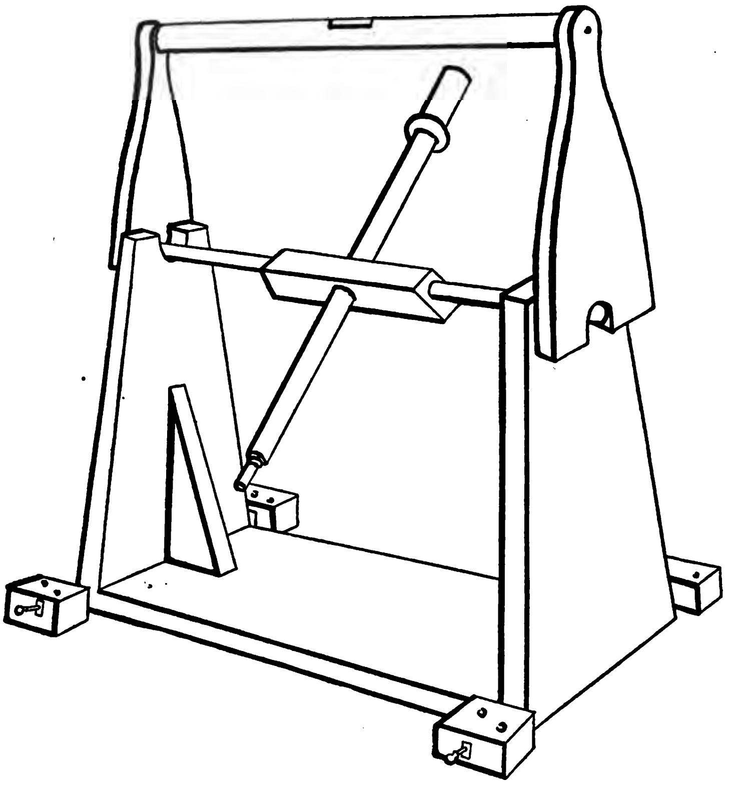

Fig. 1.—Home-Made Transit Instrument.

When not in use, the level and the telescope with its axis must be kept where they are fully protected from the weather, and it is desirable to cover the frame at least with enamel cloth (§ 1).

11. **Jointed-rods and protractor.**—A simple device for measuring altitude and azimuth is obtained by riveting together two

wooden rods, like rulers. For the width of ½ inch, 18 inches is a convenient length. One free end should be pointed, and each rod move easily on the other, though not too easily; for, after they have been opened to measure the sun's altitude, for instance, they must be kept unchanged in direction till the angle between them is read off from a protractor (§ 19).

The foundation for the protractor may be a wooden disk about 15 inches in diameter, with one side curved to prevent warping. On the other side, which should be as nearly plane as possible, mount a paper protractor, divided into quadrants and graduated at least to degrees.* The whole should then be finished with several coats of shellac and varnish.

12. The Circles.—An altazimuth instrument is the most serviceable for measuring angles in reference to the horizon, as one pointing at a body gives both altitude and azimuth. An instrument of this kind, called the Circles, is sufficiently accurate for naked-eye observers. As illustrated in Fig. 2 on the following page, it consists of an upright shaft, about five feet high, and two circles, one vertical, for measuring altitude, the other horizontal for measuring azimuth. The former, made like the protractor described in the preceding section, is attached to the upper part of the shaft, and when adjustments are properly made, the line connecting the zero marks, from which altitudes are reckoned, should be truly horizontal. The other circle, which forms the base of the instrument, is made somewhat larger and braced on the under side with heavy cleats. Its graduations are clock-wise and continuous, but those of the vertical circle are divided into quadrants.

The upright, which turns in the lower circle, is shod with iron and fits into an iron socket so as practically to plumb itself, and an offset near the top brings both pointers into the same vertical plane.

This instrument is commonly used on a meridian line already established, and in or near a building containing a large amount

* Accurate protractors of good size may be obtained from Keuffel and Esser, New York.

of iron, otherwise it might be well to have all metal parts made of zinc, as the pocket compass could then be used in adjusting.

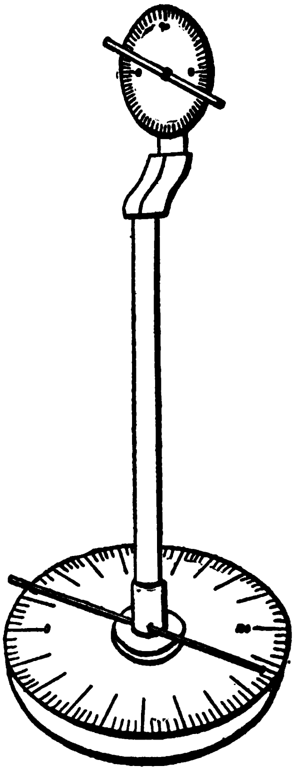

FIG. 2.—The Circles.

13. **Horizontal sun-dial.**—The sun-dial, illustrated in Fig. 3, has one marked peculiarity; the style is in reality a shaft of sunlight. To economize space, as well as to aid in adjustment, the base is half, instead of a whole circle. It has a radius of about 15 inches, and is constructed like the base of the Circles (§ 12), with a block placed, however, at the middle of the diameter for supporting the style, or what should perhaps be called the frame of the style. This, in the instrument described, is simply part

of a wooden ruler, 22 inches long, with an aperture rather more than an eighth of an inch wide, extending nearly its whole length.

By means of an accurate triangular pattern, the ruler is placed so that its angular elevation above the dial face is just equal to the latitude of the place. It should be attached to the block by

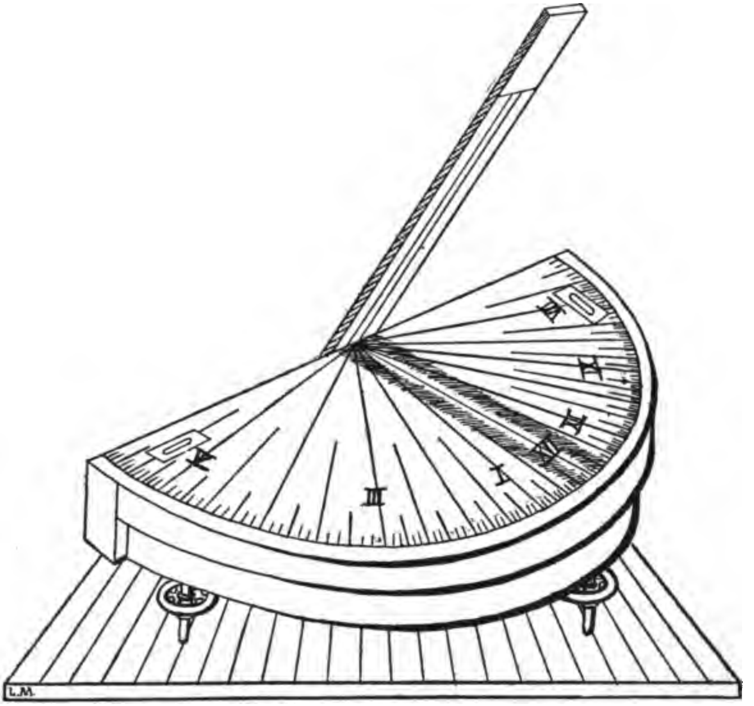

FIG. 3.—Open-Style Sun-Dial.

screws, so that slight adjustments are possible, and a plumb line is serviceable in testing whether the central line of the aperture lies in the same vertical plane as the noon line.

In adjusting the horizontal sun-dial, it is customary to place the completed instrument upon a meridian line already determined. The opposite method may, however, be employed. Thus, after the style is in place, but before any graduations are

made, the base may be fixed securely just where the dial is to be used, and the meridian line drawn directly upon it, somewhat as described in § 6. Then the sheet of paper with the required graduations is simply fastened to the base, with the noon line passing through the center of the style and coinciding with the meridian line.

The main graduations are in hours, and these are subdivided into five-minute spaces. Morning hours are marked to the right, as one faces south, and afternoon hours to the left, extending from 6^h A.M. to 6^h P.M.; but the extreme divisions in either direction are rarely used, for sun-dial readings should, as a rule, be taken during the three hours before noon and the three after, so as to obtain a strong, sharp shadow, or a bright beam of light. The moving shadow or beam of light takes the place of hands on a clock, and to tell time by the dial is to note their position in reference to the graduations. To read the sun-dial commonly means to record the time from a watch when they lie centrally over one of the graduations, or symmetrically between two of them.

Since the graduations vary with the latitude, the angular deviation of each line from the noon line must be calculated for the place where the dial is to be used. The common formula is that given under "Dialling" in the "Encyclopædia Britannica,"

i. e.,
$$\tan a = \tan t \sin \phi,$$

where ϕ is the latitude of the place, t the time, and a the corresponding arc on the dial.

14. **Miscellaneous appliances.**—In addition to the home-made instruments already described, the following appliances are important: straight edge, pocket compass, steel scale, transparent protractor, carpenter's level, orrery, celestial globe, opera-glasses, and small telescope. The level is required in adjusting the common gnomon and sometimes with other instruments. An orrery is needed to illustrate the real movement of the planets in reference to the sun, and their different aspects, conjunction,

opposition, and quadrature. The celestial globe is serviceable in many ways, especially in checking the observed positions of heavenly bodies and finding their rates of motion. It aids also in supplementing the phenomena seen at one place by those visible at the equator, poles, and other distant points. In a word, the celestial globe checks, connects, extends, and generalizes the beginner's observations.

Magnifying power for studying the heavens is perhaps best given at first by opera-glasses. Those having a power of two or three diameters show detail on the moon, and resolve some double stars and star clusters. A telescope is the last, rather than the first instrument to be obtained. The danger is that it will be only a pretty toy, but even as a plaything it has its uses, and one can be put together with little expense. For a full description of a method that may be employed, see Appendix A of the writer's "Laboratory Manual in Astronomy." Instead, however, of making the tubes, much labor is saved by using mailing tubes, or tin tubes, of suitable size. In the second chapter of this manual are to be found also additional details about the simple kinds of apparatus considered in the foregoing pages.

Works of reference should include a large star atlas, large map of the moon, the "American Ephemeris and Nautical Almanac" (§ 34), and some elementary work on practical astronomy like, "Comstock's Field Astronomy for Engineers," or "Campbell's Elements of Practical Astronomy." Each student should have small star-maps with reference circles, and a common almanac. For the eastern section of the country, the Old Farmer's Almanac is serviceable and Dr. Jayne's for the south and west. The former has the advantage of being free from medical advertisements, and that is also a characteristic of the Atlantic Monthly Almanac.

15. Preliminary definitions—The following definitions contain nothing original, but so many of them are needed immediately in observing that they are entered here in concise form for the convenience of teachers and students.

1. The celestial sphere of astronomers is one with infinite radius, and finite space as center. Its inner concave surface forms our heavens where sun, moon, stars, and other heavenly bodies appear.

2. The zenith is the point in which an imaginary plumb line, passed through the observer's position and prolonged upward, cuts the celestial sphere.

3. The nadir is the point exactly opposite the zenith in the celestial sphere underneath.

4. The visible horizon is the line where the earth and sky seem to meet.

5. The sensible or true horizon is the great circle in which the plane, passing through the observer's eye and perpendicular to the plumb line, cuts the celestial sphere (Young, Art. 15).

6. Vertical circles are great circles of the celestial sphere, which pass through the zenith, and are perpendicular to the horizon.

7. The foot of a vertical circle is the point where it intersects the horizon.

8. The vertical circle passing through the pole is the celestial meridian (*19, 20*).

9. The prime vertical is that vertical circle which is at right angles to the meridian.

10. The altitude of a heavenly body is its angular distance above the horizon, measured on a vertical circle passing through the body.

11. The zenith distance of a heavenly body is the complement of its altitude.

12. The azimuth of a heavenly body is the arc on the horizon, measured from the south point (*22*) westward to the foot of the vertical circle, passing through the body.

13. When the altitude is zero, the other coördinate (*33*) is often called amplitude and reckoned from the east or west point.

14. The north and south poles of the celestial sphere are the points where the earth's axis prolonged pierce the sphere.

15. The celestial equator is the great circle of the sphere, passing midway between the poles.

16. **Parallels of declination** are small circles of the sphere which are parallel to the celestial equator.

17. **Hour-circles**, called also circles of ~~declination~~, are great circles of the sphere passing through its poles, and perpendicular to the celestial equator.

18. **The foot of an hour-circle** is the point where it intersects the celestial equator.

19. The hour-circle which passes through the zenith is the **celestial meridian** (*8*).

20. In general, the **celestial meridian** is defined as the great circle of the sphere which passes both through the pole and through the zenith.

21. **The southing** of a heavenly body is the instant when it crosses the meridian, and it signifies also the crossing itself.

22. **The four cardinal points** are, the north and south points, where the meridian intersects the horizon, and the east and west points, where the prime vertical intersects the horizon.

23. **The declination** of a heavenly body is its angular distance north or south of the celestial equator, measured on the hour-circle passing through the body. It is called positive and marked with the plus sign when north, negative and marked with the minus sign when south.

24. **The hour-angle** of a heavenly body is measured westward on the celestial equator, from the foot of the meridian to the foot of the hour-circle passing through the body.

25. **The ecliptic** is the great circle of the celestial sphere in which the sun appears to make its annual circuit of the heavens, or it is the circle marked out on the sphere by a plane passing through the earth's orbit.

26. **The equinoxes** are the points where the ecliptic and equator intersect, and they are also the instants of time when the sun reaches these intersections. That is, when it crosses the equator going north, that instant is called the vernal equinox, and when it crosses going south, that instant is called the autumnal equinox.

27. The solstices are the points in the ecliptic farthest north and south, and they are also the instants of time when the sun reaches these points.

28. The angle at which the ecliptic is inclined to the celestial equator is called the obliquity of the ecliptic.

29. The right ascension of a heavenly body is the arc on the celestial equator, measured eastward from the vernal equinox to the foot of the hour-circle passing through the body.

30. Circles of latitude are great circles of the celestial sphere passing through the pole of the ecliptic, and perpendicular to that circle.

31. The celestial latitude of a heavenly body is its angular distance north or south of the ecliptic, measured on the circle of latitude passing through the body.

32. The celestial longitude of a heavenly body is the arc on the ecliptic, measured eastward from the vernal equinox to the foot of the latitude-circle passing through the body.

33. The coördinates of a heavenly body are the two angular measures which fix its position on the sphere. Thus, altitude and azimuth are a pair of coördinates, so also are right ascension and declination.

16. Independence in observing.—To see with one's own eyes, and to make one's own record of what is seen are essentials in astronomical observing. Consultation about estimates and measures is not admissible, nor comparison of results as they are entered in the notes. In so far as any observation is biased by what others see and do, in so far it is worthless (Byrd, § 2). Independence is the corner stone of good observing.

17. Rules for recording.—The note-book record constitutes an integral part of every observation, and should be made according to the following rules.

1. Begin the record for each evening on a new page.

2. At the head of every page, name the place of observing, day of week, day of month, and the year.

3. Name in connection with each observation any instrument employed, describing it if possible when first used.

4. Write out notes in detail, so that others following them could take the same observation in the same way.

5. Keep all records of direct observation in pencil, and make in ink any corrections necessary. This is the fundamental record which no copy can supersede.

6. Make no use of an eraser in recording essentials, but if something has been set down inadvertently, cross it out, and interline above.

7. In general, do not reject an observation once taken. The fact that it is discordant when compared with others of the same series is never a reason for rejection.

8. Decide on the last figure to be retained in making any kind of record, and then abide by that limit. Thus, if right ascension on the globe is to be read to minutes, do not at times write halves or thirds of a minute. Bear in mind also that zero is really a figure, and should be entered just as 3 or 8 would be.

9. The fraction beyond the last figure retained should be counted as a whole unit, if it is over a half, if less, it should be rejected. When it is exactly half, follow some definite rule so that it will be retained about as often as discarded. Thus, for example, count a half a whole, if it "evens up" the last figure, otherwise reject it.

The precepts of this rule apply also in making numerical reductions of observations.

CHAPTER II.

POINTS IN SUN'S DIURNAL PATH; CONSTELLATIONS IDENTIFIED; STAR-MAPS; DIFFERENT KINDS OF TIME; STANDARD MERIDIANS AND TIME SECTIONS; ALMANACS; CELESTIAL GLOBE; LATITUDE; CHECKS FOR ALTITUDE AND AZIMUTH.

18. Sun's diurnal path without instruments.—The daily course of the sun in the heavens is so closely connected with length of day and change of seasons that it is of first importance in naked-eye observing. An ideal determination would require several positions to be fixed between rising and southing (§ 15, *21*), and southing and setting; but the two latter bring out clearly the shift in the path of the sun from month to month, nor are instruments absolutely essential. A rough value for noon altitude (§ 15, *8*, *10*) may be obtained by using a porch pillar or the trunk of a tree as a gnomon, and a series of rising or setting points can be traced along the horizon by eye estimates only (Byrd, § 106).

19. Sun's noon altitude and azimuth at setting with jointed-rods and protractor.—Having chosen dark glasses suited to the eyes, place the blunt arm of the jointed-rods (§ 11) on the meridian stand (§ 7), and holding it firmly in the horizontal plane, move the other one up and down till its whole line of direction points to the sun. Note for each rod whether its inner or outer edge was used in sighting, and place the intersection of the two actually employed at the center of the cross on the protractor which fixes the center of the graduations. Let the edge of one rod coincide with the line of zero degrees, and at the edge of the other read the required angle. Whole degrees are given directly by the graduations, but tenths must usually be estimated. If the habit has been formed of estimating in quarters

and thirds, call a quarter two-tenths, a third three-tenths but two-thirds seven-tenths. (See also § 17, *9*).

In making the evening observation, keep both rods in the plane of the stand with the blunt arm directed due north (§ 15, *22*), when the sun sets south of west, but when it sets north of west, turn the blunt arm to the latter point so as to avoid measuring an angle greater than 90°.

OBSERVATION—Smith College Observatory, Northampton, Mass., Friday, Oct. 5, 1906. I measured the sun's noon altitude today and its azimuth at setting, using jointed-rods and protractor as described above. The results obtained and the checks from almanac (§ 28) and globe (§ 29) are as follows:

TABLE I.—SUN'S NOON ALTITUDE AND AZIMUTH AT SETTING.

TIME.	ALTITUDE AT NOON.	CHECK FROM ALMANAC.	TIME.	AZIMUTH AT SUNSET.	CHECK FROM GLOBE.
$11^h\,45^m$	43°.5		$5^h\ 9^m$	83°.2	
52	44 .0		10	83 .0	
55	43 .8		11	83 .5	
Means 11 51	43 .8	43°.1	5 10	83 .2	82°.3

(B. G. F.)

Dark glasses, rods, and protractors need be provided for only about half the number that are to observe on the same day, as some will be recording their notes while others are sighting and measuring. One meridian stand meets the needs of four or five students, but there should be ample space on a firm level surface for resting protractors.

Not only is sun noon the time for locating the most critical point in the sun's diurnal path; but it is also favorable for determining latitude (§§ 43, 44), drawing a north and south line (§§ 6, 61), and finding the error of a watch (§ 61, Obs., § 62, Obs. 1), so it is desirable to make careful provision for observing at this time.

20. Constellations identified.—Star-maps with fundamental reference lines (§ 21) should be used in beginning the study of the constellations. Having a list of those that are to be identified first, fix in mind their names, note the maps where they are to be found, and the groups of stars that characterize them, as the "dippers" in Ursa Major, and Ursa Minor, and the row of three bright stars in Aquila.

In the evening, let the place for observing be as free as possible from artificial lights. Begin with some conspicuous constellation near the horizon. Identify its prominent stars and when these are recognized with certainty, make use of them in picking out another constellation, and so pass to a number, along the horizon and higher up in the heavens.

After ten or fifteen have been found thus, there should be a short exercise in a lighted room, so that the configurations seen in the sky can be compared with those on the maps.

Observation.—S. C. O., Northampton, Mass., Monday, Sept. 30, 1907. Notes were not required on the first evening when constellations were found in the sky, and so the list given below includes all that have been identified on both the first and second night of observing.

Table II.—Constellations Identified.

About the Pole.	*Near East Horizon.*	*In the South.*	*Near West Horizon.*
1. Ursa Major.	1. *Andromeda.	1. Sagittarius.	1. Boötis.
2. Ursa Minor.	2. Triangulum.	2. †Aquila.	2. Corona.
3. Cassiopeia.	3. †Pegasus.	3. *Capricornus.	3. Scorpio.
4. Perseus.	4. *Pisces.	4. Delphinus.	4. *Ophiuchus.
Near the zenith, *Cygnus, Lyra.		5. *Serpens.	5. Hercules.

Constellations were not considered identified till I had found them independently both in the sky and on the map. Those marked with a star, I found in the first place by myself; and for those marked with a dagger, I found more stars than were pointed out to me. (A. E. S.)

21. **Star-maps.**—Maps of the heavens, though in some respects like those of a common geography, require careful examination before observations begin (§ 20). Most of the important points are illustrated by Map IV of Young's Uranography, where the heavy line through the middle of the page represents the celestial equator (§ 15, *15*). From it, heavenly bodies are located by measuring eastward along the line, and to the north or south of it, as in referring towns to the terrestrial equator. To aid in making measures, two sets of auxiliary lines are drawn, one parallel, the other at right angles to the celestial equator. Those parallel are called parallels of declination (§ 15, *16*), and those perpendicular, hour-circles (§ 15, *17*). There may be an indefinite number in either set. On the map named, parallels of declination are separated by 10 degrees, and the number of degrees that each line lies north or south of the equator is marked on either side of the page. The hour-circles, separated by 15 degrees of arc measure or one hour of time, are numbered with Roman figures, from I to XXIV or 0, beginning at the vernal equinox (§ 15, *26*).

The eastward measurement, corresponding to longitude on the earth, is called right ascension (§ 15, *29*), and all celestial objects on the hour-circle II or XX, for instance, have a right ascension of two or twenty hours respectively. The measurement north or south, corresponding to latitude, is called declination (§ 15, *23*), and objects on the 10 or 20 degree-line above the equator have north declination of 10 or 20 degrees. The right ascension and declination of objects between the lines may be estimated by the eye, or measured by strips of rectangular paper (§ 39).

The constellations in which the stars have been grouped from time immemorial are outlined on most star-maps by irregular boundary lines, much as the confines of states are indicated on terrestrial maps. Other lines are often used to mark out striking configurations of stars as, "the cross of Cygnus" and "the great square of Pegasus." Some of the bright stars have individual names, as Vega in Lyra, and Altair in Aquila; others are desig-

nated by numbers or English letters, but for most stars given on small maps, Greek letters alone are used, *α* being usually assigned to the brightest star in a constellation. Thus, Vega is also *α* Lyræ (Young, Art. 422).

22. Apparent, mean, and standard time.—The sun in the sky controls apparent or sun time. The instant when it crosses the meridian marks apparent noon, and at any moment its hour-angle (§ 15, *24*) is apparent time. Since, however, the real sun does not mark off days and hours of exactly the same length, it is necessary, in regulating clocks and watches, to make use of a fictitious or mean sun, which moves at a perfectly uniform rate (Young, Art. 55).

This mean sun controls mean time which never differs largely from sun time (§ 36). The instant when it crosses the meridian of a place marks local mean noon, and at any moment its hour-angle, reckoned from the local meridian, is local mean time. This kind of time was long used in the practical affairs of life; but some years before the close of the last century, railway travel gave rise to the troublesome question, "How far on either side does the time of one meridian extend?" This difficulty was finally settled by establishing standard meridians exactly one hour apart, and standard time now in general use is thus defined. The mean sun controls standard as well as local mean time. The instant when it crosses the standard meridian of a given time section marks standard noon, and at any moment its hour-angle, reckoned from the standard meridian, is the standard time of that section.

From the definition of local time, it follows that exactly at the standard meridian, standard time is local time, so standard time may also be defined as the local time at the standard meridian.

23. Standard meridians and time sections.—Standard meridians for reckoning time are in use in all parts of the world, being uniformly named by the number of degrees they are east or west of the Greenwich meridian. The four in our country are

75, 90, 105, and 120 degrees west of Greenwich, each giving its time to the territory lying within about 7½ degrees of longitude on either side of it. There are then four standard times, designated as follows:

Eastern time,	with	Stand.	Merid.	75°	or	5^h	west	of	Greenwich
Central	"	"	"	"	90	"	6	"	"	"
Mountain	"	"	"	"	105	"	7	"	"	"
Pacific	"	"	"	"	120	"	8	"	"	"

Hereafter in observations and exercises, reference is usually made to these times by their initial letters, as E. S. T. for the first and C. S. T. for the second.

A fifth division of standard time, that of the 60th meridian is employed in eastern Maine for points situated east of Vanceboro. As here indicated, the change from the time of one meridian to that of another is not usually made at the meridian precisely midway between two standard meridians, but along an irregular line depending upon the exigencies of railway systems and connections. There are also places in our country which retain local time, using standard as railway time. This is likely to occur where the difference between the two times is large, that is, where a town or city is about equally distant from two standard meridians. Detroit, Mich., in longitude $5^h\ 32^m$ W. (Appendix) for a long period made use of both kinds of time.

In spite, however, of some deviations from the theoretical scheme, the rule commonly holds that the time kept at any place is that of the standard meridian which is nearest in longitude. Thus, Omaha, Neb., in longitude, $6^h\ 24^m$ W. keeps the time of the 6^h meridian, being a little nearer that standard meridian than the one farther west.

24. Jayne's Almanac.—Jayne's Almanac is one of the best of the small almanacs for reference in elementary astronomy. (Byrd, Chap. III.) On the first page are the technical symbols and abbreviations used in the calendar, with the necessary explanations. The current page for the month, as is seen by re-

ferring, for instance, to September, contains a number of facts about different heavenly bodies. There is a column given to aspects of planets and southing (§ 15, *21*) of bright stars; for the sun, there are times of rising and setting, "sun fast" (§ 36) and length of day; for the moon, times of rising, setting, and southing, place on the sphere, and diagram of moonlight hours. The latter is helpful in preparing for observations. Thus, it shows at a glance that Sept. 29, 1911, was favorable for lunar study, as the crescent moon was visible between 6 and 10 P. M. On the other hand, any evening of the preceding week was suited for observing planets, stars, and Milky Way, for there was then no moonlight to interfere.

Jayne's Almanac is calculated for different latitudes, and so is adapted to different sections of the country. For example, that for latitude 40° is the one to employ in Illinois, Kansas, Colorado and other states named on the calendar page. The times given are the local times of the meridian 5 hours west of Greenwich; but several hours of longitude have little effect on the local time of astronomical phenomena (Byrd, § 42). So it follows that this almanac, rightly selected for latitude, would be directly applicable in many states if local time were employed. For standard time, corrections are required (§ 38).

25. **The Old Farmer's Almanac.**—This almanac is designed for New England and can be closely adapted to all sections by a table of differences in longitude, given in the introduction. In any locality, however, it will be found convenient for reference, as it contains rather more than the average amount of astronomical data, carefully arranged. For each month, there are two calendar pages which, in addition to the usual phenomena of sun, moon, and planets, include the sun's declination from day to day.

Note that "sun fast" here is not the equation of time (§ 36), but the difference between apparent and standard time (§ 22), so that the change from one to the other is made directly without passing through mean time (Byrd, § 37, Ex.).

Whatever almanac is employed, a copy should be placed on file each year, as there is often occasion to refer to back numbers.

26. Celestial globe.—The celestial globe gives in miniature a representation of the celestial sphere (§ 15, *1*), but as it is the outer surface which is shown, what is to the left, *i. e.*, east on a star-map, is to the right on the globe, though for both, east is always toward increasing right ascensions. Except for change in direction, the constellations appear much as on star-maps, and there are the usual reference circles. The celestial equator is commonly divided into 15-degree or hour-spaces by 24 hour-circles which are numbered consecutively from the vernal equinox, parallels of declination are separated from the equator and from each other by 10-degree spaces (§ 21); and on some globes, degrees on the ecliptic (§ 15, *25*) are numbered on the upper side in thirties to facilitate the reading of celestial longitude (§ 15, *32*), and dots below mark the approximate position of the sun for each day of the month.

The graduated ring which holds the globe in its supporting frame serves as the celestial meridian (§ 15, *20*), and the wide plate of the frame, for the horizon (Young, Arts. 524–526).

27. Declination of zenith equal latitude.—According to one of the common definitions, latitude equals the altitude of the pole at the given place. It follows, therefore, that latitude equals the declination of the zenith. This is shown by Fig. 4 where,

1. $N\ Z\ S$ is the upper half of the meridian.
2. N and S north and south points.
3. P the pole and Z the zenith.
4. Q the point where the equator intersects the meridian.

Now, NZ or $NP+PZ=90°$, as it is the distance from zenith to horizon, and PQ or $PZ+QZ=90°$, as it is the distance from the pole to the equator. Therefore $NP+PZ=PZ+QZ$, or $NP=QZ$. But NP is the altitude of the pole, and QZ is the declination of the zenith, for it is the angular distance of the zenith

from the celestial equator measured on the hour-circle (§ 15, *19*) passing through the zenith (§ 15, *23*). The declination of the zenith, therefore, equals the latitude.

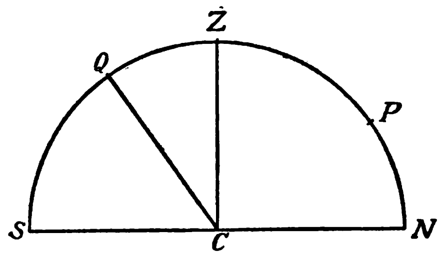

FIG. 4.

Two minor inferences follow, first, for any position of the globe, the zenith (§ 15, *2*) is just opposite that point on the meridian ring where the reading for declination equals the latitude of the place. Second, the altitude of the equator at the point where it intersects the meridian, *QS*, Fig. 4, is equal to the co-latitude, for it is the complement of *QZ*, the equal of the latitude.

28. Sun's noon altitude checked from declination.—Since the noon altitude of the sun is measured on the meridian, if it is above the equator, its altitude may be represented by *SS′*, if

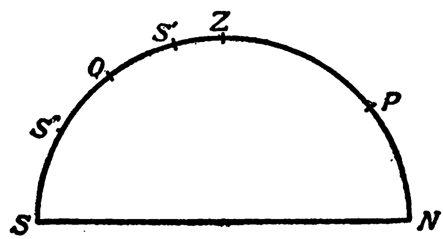

FIG. 5.

below by *SS″*, Fig. 5, and the corresponding declinations, by *QS′* and *QS″*. The latter quantities, as they can be taken from an almanac, may be considered known quantities. Moreover, *QS* is known whenever the latitude is known, as it is its comple-

ment (§ 27), so the altitude *SS′* is obtained by adding *QS′* to *QS*, and the altitude *SS″*, by subtracting *QS″* from *QS*. Since, however, south declinations are negative, the general rule for finding altitude is, add algebraically the sun's declination for the date to the meridian altitude of the celestial equator at the given place.

EXERCISE.—Given the sun's noon altitude 43°.8 as observed, Oct. 5, 1906, Northampton, Mass. (§ 19); required the check from the sun's declination.

The different steps may be arranged as follows:

Latitude of place, or declination of zenith,	42°.3
Meridian altitude of celestial equator,	47 .7
Sun's declination fr. p. 24, O. F. Almanac,	−4 .6
Sun's altitude fr. declination,	43 .1
Sun's altitude fr. observation,	43 .8
Error of observation,	0 .7

In like manner, a check is obtained for the meridian altitude of the moon (Byrd, § 32, Ex. 2), or for any body with known declination.

29. Altitude and azimuth checked on globe.—Since the most important altitude, that on the meridian, can be checked arithmetically from declination (§ 28), the globe is not often required for this coördinate (§ 15, *33*), but it is in constant requisition in checking azimuth (§ 15, *12*), especially the sun's azimuth at setting. One method consists simply in bringing to the horizon plate the dot which marks approximately the sun's position for the day (§ 26), and reading the degrees for azimuth found just opposite. It is better, however, to take account of the altitude of the sun when the observation was made; for while at sunset, that is theoretical zero, practically it is a degree or more, owing partly to the fact that the visible horizon (§ 15, *4*) is seldom in

the plane, determined by the level, from which observations are made (§ 15, *5*), and partly to the necessity of beginning the record, when the sun is a little above the horizon, in order to obtain several readings (§ 30, Obs.). A check that is usually satisfactory is, therefore, obtained as follows:

Orient the globe for latitude (§ 40), mark off the observed altitude near one end of a narrow strip of paper which serves as a vertical circle (§ 15, *6*), pass the other end through the zenith point (§ 27), and turn the globe till the upper mark for altitude coincides with the dot for the sun, and the lower, with the horizon plate. The azimuth read opposite the latter mark gives the required check.

If very precise results are desired, orient the globe for the time and place of observation (§ 40), and see that it is held in position, *i. e.*, "clamped," by crowding something soft between the ball and horizon plate. Take from the Ephemeris, for the given date, the coördinates of the sun, locate it on the globe (§ 51, Ex. 3), and through the point thus fixed, and that for the zenith, pass a strip of paper as above. The intercept between the plate and the sun's place gives its altitude, which may be evaluated in degrees by laying the paper on one of the graduated circles of the globe. The corresponding azimuth is read, of course, where the paper strip meets the horizon plate.

This is a method that serves in checking any altitude and azimuth of any body, though for values between the meridian and horizon, no further test is usually required than that given by plotting on rectangular paper (§ 80).

CHAPTER III.

Sun's Diurnal Path; Planets Identified; Constellations Mapped; American Ephemeris; Changing from One Kind of Time to Another; Plotting on Star-Maps; Orienting Celestial Globe.

30. **Sun's diurnal path with Circles.**—In setting up the instrument (§ 12) on the meridian stone, it is well to handle the base and upright separately to prevent jars. Adjust so that the graduations for 0° and 180° come exactly over the meridian line, and level the base as accurately as possible, using a carpenter's level for testing, if there are no level vials in the base itself.

To "set" on the sun, turn the upright shaft, and, with a hand on the clamp at the back, move the pointer of the vertical circle till it seems to pierce the sun, being careful meanwhile not to use the upright in any way as a support. It should be left free to plumb itself. After the final clamping has been made and both hands removed, see that the direction of the upper pointer is unchanged; and then be on guard against disturbing either pointer in the few moments between calling "time" to the recorder, and making readings for altitude and azimuth. These should be taken opposite the center of each pointer, but if it is more convenient to employ the edge, add or subtract half the pointer's diameter.

Two observations, one with the vertical circle in a given position, the other after it has been turned 180° in azimuth, are required to fix a single point (Byrd, § 3); and two points, either rising and southing or southing and setting, are desirable in tracing any diurnal path of the sun (§ 18). Either pair of these critical points may be allowed to suffice in fixing four of the six paths that should be located during the year; but the other two ought to have three or more intermediate positions,

at hourly intervals, so as to bring out clearly the form of the solar path between the meridian, and the horizon on one side.

Observation.—S. C. O., Northampton, Mass., Tuesday, May 21, 1907. I take today a seven-point path of the sun, with the Circles adjusted on the second, south meridian stone. A strong wind interferes with accurate settings.

The data in full, obtained at noon and sunset, with the usual checks (§§ 28, 29), are as follows:

Table III.—Data for Sun's Diurnal Path, Northampton, Mass.

Date, May 21, 1907.	Altitude at Noon.	Azimuth.	Circle.	Time.	Altitude.	Azimuth at Setting.	Circle.
$11^h 49^m$	68°.8	2°.0	West	$6^h 46^m$	3°.1	115°.2	North
50	67 .8	2 .3	East	47	2 .1	115 .0	South
52	67 .4	4 .0	East	49	2 .0	115 .0	South
53	68 .6	3 .0	West	50	2 .3	116 .0	North
Means 11 51	68 .2	2. 8		6 48	2 .4	115 .3	
Ck. fr. Decl.	67 .7			Ck. fr. Globe		114 .6	
Error	0 .5			Error		0 .7	

The mean results of the five intermediate positions are:

Time........	$12^h 56^m$	$2^h 4^m$	3^h ¿^{m}	$4^h 32^m$	$5^h 34^m$
Altitude.....	64°.0	53°.7	42°.6	26°.8	15°.2
Azimuth.....	39 .1	63 .4	78 .4	93 .7	103 .5

(E. W. J.)

In taking a series of observations like that above, the instrument used, after being carefully adjusted, should, if possible, remain undisturbed throughout the whole operation. Points between the meridian and the horizon are satisfactorily fixed by two readings, with opposite positions of the vertical circle.

31. Sun's diurnal path with solar-image gnomon.—The required observations, with this gnomon, consist merely in placing a dot, a number of times, at the center of the sun's image.

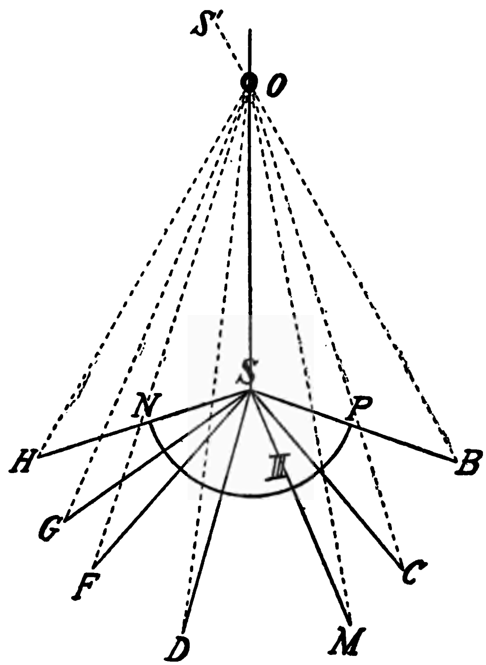

FIG. 6.

The method of deriving, from these dots, the sun's coördinates, is illustrated by Fig. 6, where,

1. *O* is the center of aperture used.
2. *SM*, the meridian line in O's vertical plane.
3. *S*, south point of meridian line.
4. *B*, *C*, *M*, *D*, *F*, *G*, *H*, points marked in observing.
5. *SB*, *SC*, etc., bases of triangles, right-angled at *S*.
6. *BO*, *CO*, etc., lines showing the direction of the sun.
7. *P III N*, semicircular protractor.

When the protractor has been properly adjusted, with the center of graduations at S, and the radius of zero degrees coinciding with meridian, No. III, azimuths are read directly at the points where the base lines, as SB and SC, intersect the graduated arc. In making these readings, one point requires attention. Since the sun is, of course, on the opposite side of the meridian from its image, when that is found a little west of the meridian line, as at C, the sun's azimuth is nearly 360°, or it may be expressed as a small negative angle.

To obtain altitudes, note, for example, that in the right-angled triangle, OSB, BO is the line of direction toward the sun, and BS is in the plane of the horizon, therefore the angle OBS is the sun's angular elevation above the horizon, that is, its altitude, when the center of the image is at B. If desired, this angle may be obtained without calculation. Thus, lay off SO and SB on plotting paper at right angles to each other and in correct proportion, mark the line BO, and then place a transparent protractor on the paper, so as to read the angle at B, or cut out the paper form OBS and measure the angle from the mounted protractor, described in § 11.

The solution by trigonometry is really shorter, for, as OSB is a right angle,

$$\tan OBS = \frac{SO}{SB};$$

and if the numerical values of the following observations are substituted, the computation is as follows:

log 20.00,	1.3010
log 7.56,	0.8785
log tan 69° 18,	0.4225

Observation.—Normal College, New York, N. Y., Thursday, May 29, 1913. The gnomon that I employ to find the sun's path is, in general, like that described in § 5. The "plate glass" is about 4 ft. wide, but its height is only 25 in., and the upper part is not available on account of the shadow of the

frame. The projecting board is 6.5 ft. long, 2.5 ft. wide, and has three meridian lines marked on it. I make use of the one numbered III, reckoning from the east, and at six different times, fix by dots the center of the sun's image.

To find the corresponding coördinates of the sun, azimuths are read from a protractor and altitudes calculated as described above. The mean of three measures of the common side *OS* is 20.00 in., and the other data obtained are as follows:

Times.	Bases.	Azimuths.	Altitudes.
$11^h\ 21^m$	$7^{in.}.56$	$-23°.2$	69.3
51	6 .94	− 3 .5	70.9
12 21	7 .28	+17 .2	70.0
52	8 .36	+36 .2	67.3
1 24	10 .17	+51 .0	63.0
2 15	14 .08	+67 .8	54.8

From the azimuths and altitudes in the last two columns, I plot the sun's path for today on rectangular paper, and find that a smooth curve passes almost exactly through all of the six points (§ 80). (J. C. D.)

The second observation is so near noon that the angle for altitude, 70°.9, may be checked from the Ephemeris. There, the sun's declination for the given date is found to be 21°.6, making the theoretically correct altitude 70°.8 (§ 28). While no observations were taken late in the afternoon, and there is thus uncertainty in the prolonged curve, it indicates that the sun set between 30° and 35° north of the west point. The globe check gives 30°.

With regard to dates for observing the diurnal path of the sun, it is a good arrangement to locate three in the fall, the last near the winter solstice (§ 15, *27*); and three in the spring, one near the equinox (§ 15, *26*) and the third not far from the summer solstice (§ 80). As a rule, three weeks or more should intervene between different observations, though an extra path may well be inserted at equinoxes or solstices.

All instruments are used to better advantage if they are examined before observations are taken. Thus, with the Cir-

cles, it is well, in some day laboratory period, to note how the graduations are made and numbered, to practice taking readings; and if possible, measure the altitude and azimuth of some terrestrial object where there is no need of dark glasses or illumination.

32. **Bright planets identified.**—The five planets known to the ancients, Mercury, Venus, Mars, Jupiter, and Saturn are bright bodies, readily seen by the unaided eye. There are various ways of identifying them. If Sirius and a few other conspicuous stars are known, it is often possible to pick out Venus and Jupiter by their brightness alone; and in general, when any bright star-like body is seen in the heavens, where no corresponding object is found on the map, it is probably a planet, and any doubt can be removed by looking a few nights later to see whether it has changed its position in reference to neighboring stars.

The small almanacs (§§ 24, 25) give data that are helpful in finding a single planet, or in locating all, and distinguishing one from another. It is well to know beforehand about each one, whether it is a "morning" or an "evening" star (Byrd, § 31), whether it is near conjunction, opposition, quadrature, or greatest elongation (Young, Arts. 289 and 290); and how it is placed with regard to the horizon, that is, when it rises, souths or sets.

One of the quickest and surest methods of identifying is to take from the Ephemeris (§ 34) the coördinates of the body required, plot them approximately on a star-map (§ 39), and then look in the sky, near the reference stars. If a bright object is found close to the map place, and its coördinates, estimated directly, agree with those given in the Ephemeris, it is in all probability the planet sought. Still, it is not amiss to look again on another night and see if it has moved. For those who are not very familiar with the heavens, it is often puzzling to know when and where to look, even after the planet's place has been found as above on a map. The simplest way, perhaps, is to refer to a planisphere or to an atlas, like "Proctor's Half-

Hours with the Stars," which depicts the principal constellations in reference to horizon and zenith at different hours, on a number of dates throughout the year.

Instead of maps, the celestial globe may be employed for locating the body (§ 51), and if it is oriented for the time and place of observation (§ 40), it shows the position of a planet with regard to the horizon, as well as among the stars. The globe gives also another means of identifying; for, when the altitude and azimuth of a body have been observed, it is only necessary to plot these coördinates on the oriented globe, and compare the place thus fixed with that obtained from the Ephemeris. This is a satisfactory way to identify Mercury and fix its place among the stars (§ 51, Ex. 1).

The common dictum, that planets do not twinkle, gives little if any help to beginners, in making identifications.

OBSERVATION.—Denver, Colo., Friday, Feb. 25, 1910. To aid in finding Saturn tonight, reference is made to Jayne's Almanac. There it is seen (p. 9) that the planet comes into conjunction with the sun April 16; and interpolation between the times of setting given for February and March makes the time for Feb. 25, $9^h\ 20^m$ P. M. (§ 50, Ex. 1), standard as well as local (§ 38, Ex. 4). Saturn should, therefore, be visible in the west in the early evening.

I look in that quarter of the sky at 7^h P. M., and find an object brighter than others in the vicinity, which I think is the planet. Its place is carefully fixed by a sketch, including several of the bright stars in Pisces. About a week later, I find the same object again, near the same stars, but as its angular direction from the reference line has very perceptibly changed I conclude it is a planet. It cannot be Mercury or Venus, for at this time they are morning stars (Old Farmer's Almanac,) nor can it be Jupiter, for that planet does not rise till after 8 o'clock (Jayne's Almanac). It must then be either Mars or Saturn, but the former does not set till nearly midnight, and this object will reach the horizon long before then, so it is without doubt the planet Saturn. (M. S. S.)

33. **Constellations mapped.**—Before sketches are made of individual constellations, as many as fifteen should be easily recognized in the sky (§ 20). Those that are to be drawn first should be studied beforehand from star-maps, in the daytime, and the Greek alphabet must be thoroughly mastered (p. 6, "Young's Uranography").

To avoid delay and perplexity in beginning a map, and to insure its proper location on the page, a reference line may be fixed by a card pattern. This is simply a piece of stiff cardboard that fits exactly two sides of the record page, the other part being cut in such shape that dots marked on its edge fix the places of two prominent stars of the constellation. Working from these, either directly or indirectly, the other stars of the map are located by estimates of distance and angle, more dependence being placed upon the former. As a unit of distance, take a star-line, that is the line joining two stars, and, if possible, let it be near the distance to be measured, and approximately in the same direction with regard to the horizon (Byrd, § 6). Estimates are also facilitated by taking pains in choosing reference stars. Thus, the eye judges more accurately as to whether objects are in line than of any other configuration (§ 46, Obs.), and angles of 90° or ½ 90° are more easily estimated than others.

For the note-book record, it is a good arrangement to enter fundamental data and explanations on one page, and the map itself on that opposite. As many as seven stars should be included, and, since accuracy in their relative positions is the prime requisite, attention during observation should center on locating dots for them as carefully as possible. Later, in some day-laboratory period, the proper symbols for magnitude may be inserted.

In the evening, the first exercise is to identify with certainty the stars to be included. If the constellation to be mapped is Aquila, known already by its rows of three bright stars, others will be found somewhat as follows:

The star-line $\gamma\beta$ prolonged beyond β, rather more than its own length, meets the fairly bright star θ, and a line from that

passing toward the Milky Way, and making an acute angle with $\gamma\theta$, goes nearly through η and δ. To find ζ, pass a line through δ, nearly parallel to $\theta\gamma$ and extending about as far in the same direction. An eighth star, λ, is fixed by prolonging $\gamma\delta$ its own length beyond δ. As a check, note that $\gamma\theta\delta\zeta$ mark out approximately an oblique parallelogram.

Observation.—519 Oakland Avenue, Pasadena, Calif., Tuesday, Oct. 27, 1908. Taking $\alpha\pi$ as the reference line, I have mapped Puppis in Argo-Navis, as shown in Fig. 7, on the following page. In all, 17 eye-estimates of distance and angle have been made, but the following are the most fundamental:

1.	$\angle\alpha\pi\kappa=180°$, St. Line	5.	$\angle\zeta\sigma\pi=90°$
2.	$\pi\kappa=\frac{2}{3}\alpha\pi$	6.	$\zeta\sigma=\sigma\pi$
3.	$\angle\alpha\pi\zeta=90°$	7.	$\angle\alpha\tau\zeta=180°$
4.	$\pi\zeta=\frac{3}{5}\alpha\pi$	8.	$\alpha\tau=\frac{2}{5}\alpha\nu$

Several double stars in Puppis and the cluster about α deserve notice. For these objects, as well as for two or three faint stars, opera-glasses were used. (L. B.)

The first maps demand much patient effort. It requires practice to carry in mind a number of specifications traced on the map, and bring back from the sky the required estimates. It also demands self-control to work independently, to make estimates of distance and angle without any inquiry as to what values others are obtaining and recording, but independence is of vital importance in astronomical observing (§ 16).

Since all naked-eye study of the heavens is founded on a knowledge of the constellations, they must receive careful and repeated attention. About 35 ought to be mastered so that they are easily recognized at all times and seasons, no matter how they are placed with regard to the horizon. Maps should be made of rather more than half this number, and the others, identified by seven or more stars.

34. **American Ephemeris.**—The almanac used by surveyors, navigators, and astronomers is a large volume containing hundreds of pages. That published at Washington for our country

is called the "American Ephemeris and Nautical Almanac," and even in an elementary course is indispensable for reference.

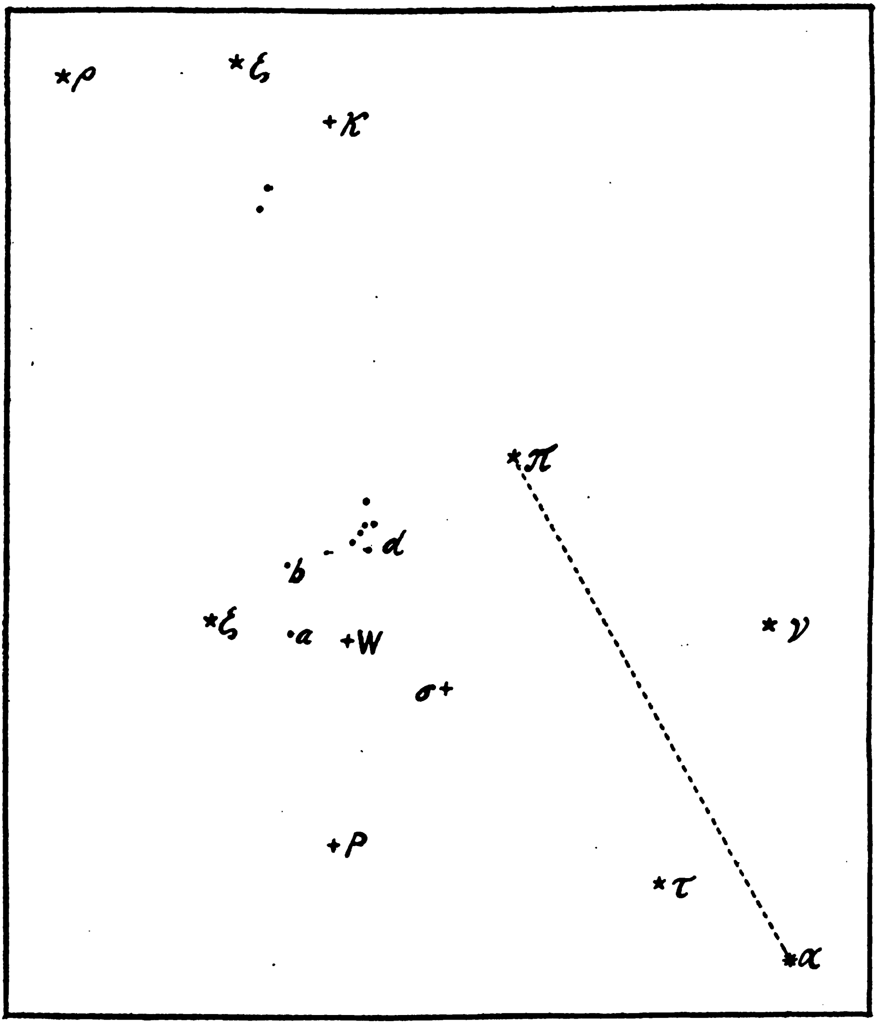

FIG. 7. Puppis in Argo-Navis.

The first part of the book is devoted to phenomena connected with the Greenwich meridian, and the sections most needed for reference are those giving the right ascension and declination of the planets throughout the year, and the same coördinates for the moon at every hour of Greenwich mean time. Immediately following the latter, there is a tabulation of the times of lunar phases for each month; and near the end of this first part is the mean longitude of the moon's ascending node, which is of use in showing graphically the position of the moon's path on the celestial sphere (§ 57, final Par.).

Part II, which is based on the Washington meridian, contains a standard star-catalogue, including both mean and apparent places. The differences between the two are inappreciable on the globe, and so the former are commonly used in fixing positions connected with naked-eye observing (§ 51, Ex. 3), but apparent right ascensions should be employed in finding time from star transits (§ 62, Obs. 2).

Under the sun, much of the data given is more directly applicable in our country than the corresponding values for Greenwich. This is especially true of the "Equation of Time," which is essential in passing from apparent to mean time, and the reverse (§ 36). In like manner the coördinates under "Transit-Ephemerides of Planets" are to be preferred for all dates given; for others, recourse must be had to Part I. The section, "Moon-Culminations" is often convenient for reference, as it shows at a glance whether the moon "runs high" or "low."

Part III, entitled "Phenomena," is that from which the makers of small almanacs derive much of their material. There are here very full details about solar and lunar eclipses, occultations of stars by the moon, phases and librations of the moon; and conjunctions and other aspects of planets. The diagrams for satellites, especially for Jupiter's system, are helpful in identifying these objects in a telescope. At the close of this part, though hardly belonging to it, is an alphabetical list of places, with latitudes and longitudes, where a number of observatories are located.

Three of the six tables, given in the latter part of the Ephemeris, require notice. Table I is used in finding the latitude of a place from off-meridian altitudes of Polaris (§ 78); Table II contains the corrections for reducing the hours, minutes, and seconds of sidereal time to the corresponding mean solar interval; and from Table III, in like manner, are taken the corrections required in passing from a mean time, to the equivalent sidereal interval.

Except for problems in time and latitude, data from the Ephemeris should usually be taken only to the nearest minute of time and tenth of a degree of arc.

35. **Civil and astronomical days.**—The civil day is the one used in the ordinary affairs of life. It is reckoned from midnight to midnight in periods of 12 hours, both noon and midnight being called twelve o'clock. The astronomical day is used in the Ephemeris (§ 34), and in astronomical records and calculations (§ 50, Ex. 2, § 60, § 72, Obs. 2). It begins at noon when the civil day of the same date is 12 hours old, and is reckoned continuously through 24 hours. The day of the month is, then, the same for both days between noon and midnight, but between midnight and noon, the astronomical date is one day earlier. In the former case the only change in passing from one date to the other is in adding or dropping the P. M. To illustrate the latter, let it be required to find what civil date corresponds to May 25, $19^h\ 32^m$, astronomical time. Since at 12 o'clock, midnight on the 25th, the civil day, May 26, begins with zero hours, 12^h is subtracted from 19^h, and one added to the date number, making the civil reckoning, May 26, $7^h\ 32^m$ A. M.

36. **Equation of time and "Sun Fast."**—The differences between apparent and local mean time (§ 22) is known as the equation of time. It is constantly changing, but so slowly that for most, if not all naked-eye exercises, the noon value for Washington may be used through the day and throughout the country.

"Sun Fast" or "Sun Slow" given in the small almanacs (§§ 24, 25) is, as a rule, simply the equation of time copied from the

Ephemeris (§ 34), to the nearest minute, the signs minus and plus being replaced by fast and slow. This use of signs in the Ephemeris is like that made by astronomers with clock and chronometer errors. Thus, if a time-piece is fast, its error is marked minus, if slow, plus.

37. **Apparent time changed to local mean time and *vice versa*.**—Apparent time is changed to local mean time by adding or subtracting the equation of time, since by definition that is the difference between them (§ 36). In applying the equation, the signs prefixed are to be taken in the sense that apparent solar time is fundamental, and mean time is derived from it by adding the equation to apparent time when the sign is plus, and subtracting it, when the sign is minus (Ephemeris 1914, p. 713). For example, if the apparent time given is $3^h\,11^m\,52^s$ P. M., March 13, 1912, the equation of time is, $+9^m\,37^s$ (Ephemeris, p. 519), and the corresponding mean time $3^h\,21^m\,29^s$ P. M. Of course, if the latter time were given and apparent solar time required, the $9^m\,37^s$ would be subtracted. So it must be fixed in mind that the signs of the equation do not necessarily signify operations, for whether a plus value is to be added or subtracted depends upon what is given and what required.

If Jayne's Almanac, instead of the Ephemeris is used, the reduction can be carried only to minutes, for sun slow is given as 10^m, *i. e.*, only to the nearest minute (§ 36).

38. **Local mean time changed to standard time and *vice versa*.**—Standard time is the local time at the standard meridian (§ 22), and hence all questions of passing from one standard time to another, from local to standard, or standard to local, are reduced to the simple problem of changing from one local time to another. The important point is, then, the connection between the local times of two meridians. In general, the eastern meridian has the faster time; for the sun, moving westward in its diurnal course, comes there first and marks an earlier noon. To find definite numerical relations, consider two stations, *A*, on the eastern meridian, and *B* on that to the west. It is, of

course, noon at A when the sun crosses the meridian there, but at B, noon will come later by as many minutes as it takes the sun to pass from A to B. This interval is by definition the difference in longitude between the two meridians (Young, Art. 61), and when that is known, either local time is readily obtained from the other.

In the two examples which follow, the mean sun (§ 22) is the one to think of as controlling the different times.

EXAMPLE 1.—If a station, A, is in longitude 20^m east of B,

(1) When it is noon at B, what is the time at A?

(2) In general, how is A's time derived from B's?

(3) When it is noon at A, what is the time at B?

(4) In general how is B's time derived from A's?

After the sun has crossed A's meridian, marking noon there, it takes 20^m to pass to the meridian at B, and meanwhile the clock at A has gone forward 20^m, so when it is noon at B, A's time is 20^m faster, *i. e.*, $12^h\ 20^m$. Since the relation between the times of the two stations is evidently the same throughout the day, it follows that for any instant at B, the corresponding time at A is 20^m faster.

On the other hand, when it is noon at A, it still lacks 20^m of noon at B, so B's time is 20^m slower than A's, at noon and at all other times of the day.

EXAMPLE 2.—If the meridian passing through A, 20^m east of B, is the standard meridian for B,

1. When it is 10^h A. M., local time at B, what is the corresponding standard time there?

2. When it is 5^h P. M., standard time at B, what is the corresponding local time?

Since standard time at B is by definition the local time at its standard meridian, it is the local time at A, but that is 20^m faster than local time at B (Ex. 1), so when it is 10^h A. M. local time at B, it is $10^h\ 20^m$ A. M. by standard time there.

Put the standard time at B, 5^h P. M., A's local time, is 20^m fast for B, making the required local time at B, $4^h\ 40^m$ P. M.

In like manner, if *B's* meridian is taken as the standard for *A*, it is easy to follow out the connection between local and standard times for places having their standard meridian to the west. Therefore, the general rules for passing from local to standard time and the reverse are as follows:

If local mean time is given and standard time required, add to the local mean time the difference in longitude between the two meridians, when the standard meridian is east of the given place, but when it is west, subtract this difference.

Conversely, if standard time is given and local mean time required, subtract from standard time the difference in longitude between the two meridians, when the standard meridian is east of the given place, but when it is west, add this difference.

EXAMPLE 3.—Given the standard time, $11^h\ 4^m$ A. M., at Raleigh, N. C., in longitude $5^h\ 15^m$ W. (Appendix); required the corresponding local mean time.

From the longitude given, it is seen at once that Raleigh's standard meridian is 15^m east of the place. So 15^m is subtracted from the standard time, giving as the required local time $10^h\ 49^m$ A. M.

EXAMPLE 4.—According to Jayne's Almanac, the southing of Polaris, *i. e.*, the North Star, (§ 15, *21*) came at $10^h\ 0^m$ P. M. (§ 64, Ex.), Friday, Nov. 12, 1909. What was its standard time of southing at Lawrence, Kan.? What, at Denver, Colo.?

Since the times of this almanac may for most purposes be treated as local for the states named at the top of the calendar pages (§ 24), the requirement is, in fact, to reduce local to standard time. But at Lawrence, $10^h\ 0^m$ local time equals $10^h\ 21^m$ standard time, the standard meridian being 21^m east of the place. For Denver, no change at all is needed, as the standard and local meridians of the place differ only 12 seconds (Appendix), and so within that limit, local agrees with standard time.

To illustrate the two steps required in deriving standard from apparent time, the following example is added:

EXAMPLE 5.—Required the clock time of sun noon at Columbia, Mo., Oct. 10, 1908, the clock being set to central standard time.

Sun noon is, of course, 12^h solar time, and this like any other hour of apparent time is reduced to local mean time by applying the equation of time. Its value is given as 13^m, under sun fast, in Jayne's Almanac, so the Ephemeris sign is minus and it is to be subtracted (§§ 36, 37). The local mean time of sun noon is, then, $11^h\,47^m$, but the corresponding standard time is 9^m faster, as the standard meridian of Columbia is 9^m east of the place (Appendix). These steps may be placed in tabular form, as follows:

Sun noon, apparent time,	$12^h\ 0^m$
Equation of time, sun fast,	-13
Local mean time of sun noon,	11 47
Standard meridian east of Columbia,	9
Standard, *i. e.*, clock T. of sun noon,	11 56 A. M.

The subject of time is a difficult one, and clock dials with hands that can be turned are helpful in gaining clear ideas (Byrd, § 34).

39. Plotting on star-maps.—Any celestial object, which has been definitely placed in the heavens, in regard to neighboring stars, can be located on a star-map, and its coördinates in right ascension and declination read from the usual reference circles (§ 21). Sometimes its place is found as accurately as required by mere inspection, and there are other observations that require but little more.

Exercise 1.—From the data given in the observation of § 46 find from "Young's Uranography," first, in what constellation the moon was located; second, near what stars.

To answer the first question, nothing is needed but to look on Map II, and note by the eye that the prolonged star-line ends in Gemini. To answer the second, mark off on a strip of rectangular paper two-thirds the distance between α Orionis and γ Geminorum, then pass the strip through the stars, so that the marked

space lies just above γ, and the point fixed by its upper end shows that the moon was about midway between ζ and δ Geminorum but a little farther north.

Exercise 2.—As an illustration of more critical plotting, let it be required to read from "Proctor's New Star Atlas" the coördinates of Mars, when the planet was observed at the intersection of the diagonals $\sigma\zeta$ and $\tau\phi$ in the bowl of "the milk dipper" (§ 59, Obs. 1).

Two narrow strips of rectangular paper, serving for these diagonals, fix the place of the planet on Map 9 of Proctor's Atlas; and show at once that its right ascension is between $18^h\,40^m$ and $19^h\,0^m$, as the hour-circles on this map are separated by 20^m. The space corresponding to 20^m, marked on rectangular paper, is 15.3 divisions, and the distance of the planet east of the hour-circle, $18^h\,40^m$, is found to be 7.6d., d standing for divisions; so the required minutes beyond the hour-circle are $\frac{7.6}{15.3}$ of 20^m or 10^m, making the entire right ascension $18^h\,50^m$.

In like manner it is seen that the planet is $\frac{9}{17.7}$ of 5°, or 2°.5 below the parallel of 25°, south declination, so the whole declination is, $-27°.5$.

In spite of the fact that the planet is rather unfavorably placed near the side of the map, these coördinates agree closely with those obtained from the celestial globe (§ 59, Table).

A problem in plotting, just opposite to that considered, arises when accurate coördinates of a heavenly body are known, and it is required to find its place among the stars on a map. The former process is then reversed, and minutes and degrees, that cannot be read directly from the map, are expressed in divisions of rectangular paper.

Exercise 3.—The position of Halley's Comet at $8^h.5$ P. M., C. S. T., May 23, 1910 was, R. A., $8^h\,4^m$, and Decl., $+11°.2$ (§ 50, Ex. 3). Required to locate the comet among the stars on Proctor's Atlas, and then fix its place critically in regard to the reference circles.

From Map 6, it is seen directly that the comet was nearly in line with Procyon and δ Cancri, and about midway between them. To place it more critically, note that on this part of the map,

$20^{m} = 17.0d$, and $5° = 17.5d$.

$\therefore \frac{4}{20}$ of $17.0d = 3.4d$, and $\frac{1.2}{5}$ of $17.5d = 4.2d$.

So the comet was 3.4d east of the 8^{h}-circle, and 4.2d north of the 10°-parallel of north declination.

Star-maps are convenient for plotting, and the best of them, though far less expensive than a celestial globe, are made with great care and exactness. But errors from projection are inevitable ("Young's Uranography," Art. 2), and the globe has the advantage of representing the heavens on a spherical surface (§ 26).

40. Celestial globe oriented.—If, as is usual, the orientation is required for standard time, five steps are necessary.

First, the globe is oriented to show the aspect of the heavens, at any place north of the equator, by raising the pole (§ 15, *14*) above the horizon plate till its altitude equals the latitude of the place, as shown on the meridian ring.

Second, the globe is adjusted for the aspect of apparent noon by bringing to the graduated side of the ring the sun's place for the day (§ 26).

Third, it is adjusted for the aspect of mean noon by taking account of the equation of time. When, for example, that is -14^{m}, the mean time of sun noon is $11^{h}\,46^{m}$ (§ 38, Ex. 5), but the mean time of mean noon is, of course, $12^{h}\,0^{m}$; so sun noon comes before mean noon, and to pass from the former to the latter, the globe must be turned forward 14^{m}, as read on the celestial equator. If the sign of this equation is plus, the globe is, of course, turned backward, *i. e.*, to the east.

Fourth, the globe is oriented for standard noon by taking account of the difference between local and standard meridians. As an illustration, assume that the standard meridian is 21^{m} east of the place, then local noon comes 21^{m} after standard noon,

and to pass from the former to the latter, the globe is turned 21^m to the east. If the meridian is west of the place the globe is turned west.

Fifth, to show how the heavens appear at any hour before or after standard noon, turn the globe the given number of hours and minutes west or east from the noon position, according as afternoon or morning hours are required.

For the most critical adjustment, it is necessary to plot the sun's place from the Ephemeris (§ 34, § 51, Ex. 2), and to take account of the difference between the hours of mean time and the sidereal time, marked on the celestial equator (§ 64).

To aid in testing the orientation, and to obtain an independent check from a sidereal time-piece, the right ascension of the meridian (§ 49) may be read in connection with all except the first of the preceding steps. Note that this right ascension increases as the globe is turned to the west, but decreases when it is turned east.

Exercise.—Required to orient the celestial globe for $8^h\ 23^m$ P. M., C. S. T. (§ 23), Oct. 14, 1907, Lawrence, Kan.

R. A. of meridian at apparent noon, from plotted position of the sun,	$13^h\ 15^m$
Equation of time, p. 406 Ephemeris, or sun fast, p. 21 Jayne's Almanac,	−14
R. A. of meridian at local mean noon,	13 29
Standard meridian east of Lawrence,	21
R. A. of meridian at standard noon,	13 8
Required interval after standard noon,	8 23
Corr. to reduce $8^h\ 23^m$ to sid. interval,	1
R. A. of M. at $8^h\ 23^m$, P. M., C. S. T.,	21 32

The final right ascension read from the globe should agree approximately with correct sidereal time at $8^h\ 23^m$ P. M., C. S. T., the time for which the globe is oriented (Byrd, § 69).

CHAPTER IV.

Sun's Apparent Motion; Latitude from Sun's Altitude; First Observations of the Moon; Greenwich Time; Sidereal Time; Interpolating; Plotting on Globe; First Tests for Opera-Glasses and Small Telescope.

41. Apparent motion of sun among the stars.—The direction in which the sun seems to move on the celestial sphere, and its approximate rate can be determined by the unaided eye. The critical part lies in connecting sun and stars, as both are not visible at the same time. This may be effected by fixing the point where the sun sets by reference, first to terrestrial objects, and later, on the same evening, from exactly the same place, locating this point in regard to the stars, by the usual alignments.

A good view of the western horizon is important, and it is desirable to become familiar beforehand with the constellations appearing first in the vicinity of the sunset point, so that on the evening of observing, the few isolated stars that come first out of the twilight can be positively identified.

Observation.—Second-story porch, facing west, 519 Oakland Avenue, Pasadena, Calif., 5^h P. M., P. S. T. (§ 23), Monday, Oct. 25, 1909. Standing by the first awning rod, I mark the sunset point in regard to distant trees; and a little before six from the same position, I begin looking for reference stars. At 6 o'clock the following estimates are made:

1. The line through β Hercules and α Serpentis prolonged its own length below α meets the horizon 5° north of the sunset point.

2. Sighting along the edge of the upright awning rod, I make the stars α Herculis, δ Opiuchi, and the sunset point in the same straight line. I estimate also that the line through α and δ prolonged $\frac{3}{4}$ its length meets the sunset point. (L. B.)

About a month later, Dec. 1, the sunset point was located

in like manner by the same observer, from the same place. The two points fixed among the stars, when plotted on the celestial globe, show that *o* Libræ was setting an hour later than the sun, Oct. 25, at approximately the same place; and that on Dec. 1, *c* Ophiuchi was close to the sunset point an hour after the sun. The distance between the stars, or to be exact, the points near them, is found to measure 32°. (L. B.)

In drawing conclusions from the data thus obtained, the stars are to be taken as fixed reference points; and, since on Dec. 1, *c* Ophiuchi though about 30° east of *o* Libræ, was setting at the same interval after the sun as *o* in October, it is evident that the sun has meanwhile been moving eastward among the stars. And, furthermore, since the stars were found at the sunset point, when practically at the same distance from the sun, the space between them, 32°, gives a measure of the sun's motion during the interval of 37 days between the observations. This makes the sun's daily rate of motion 0°.87 instead of 0°.99 as given by dividing 360° by the number of days in a year, but it is as close an agreement as the method warrants, *i. e.*, renders trustworthy. For a more accurate determination of rate, see the observation of § 63.

42. Sun's bright image under trees.—Sunlight passing through the interstices of leaves forms many images of the sun. A few are bright and well defined, others are comparatively dim; and overlapping, distorted forms are not uncommon. Doubtless, the most interesting time for observation is during a partial solar eclipse, but on any day when the sun is shining there is an opportunity to examine such images. Let them fall on white cardboard, and note whether varying its distance and angle changes their shape or size. Observe also the effect of different kinds of foliage, including shrubs as well as trees.

To test whether or not the form of the image depends upon the shape of the openings, sunlight should be allowed to pass through irregular apertures cut in paper, and held at some distance from the card on which the images fall.

43. Sun's noon altitude from the gnomon.—If the common gnomon is used (§ 5), the actual observation consists simply in marking the end of the shadow at the instant of apparent noon; but, since it is not easy to decide exactly where that comes, it is desirable to bring out the north part of the shadow sharply by letting it fall on white paper. The mark for the end is, perhaps, best placed midway between the dark part of the shadow and the outer edge of its penumbra. Final results depend largely upon using a true upright, well adjusted.

In making measures, be careful to get the whole length of the shadow, which, if a gnomon box is used, includes the width of its frame, and sometimes a little space besides, depending upon adjustment. Often, too, the height of the gnomon includes a part of the height of the box.

Observation 1.—Wide View, near Lawrence, Kansas, Saturday, Dec. 22, day of the winter solstice, 1906. Gnomon post No. 1 is adjusted in the gnomon box on the roof platform, and the end of its shadow marked within a minute of sun noon; for, during more than that interval, the length of the shadow does not change perceptibly.

Three independent measures made of each, give the length of the shadow 57.06 in., and the height of the gnomon 30.00 in. From these values, altitude is derived, as explained in § 31, the angle read from a large protractor being 27°.8, and that derived from calculation, 27° 44′. In like manner, on the day of the summer solstice June 22, 1907, the sun was observed at noon, at the same place, and its altitude from the protractor found to be 74°.7, from calculation 74° 40′.

When, as here, the determination of altitude is carried to minutes, the correction for refraction should be included (Young, Art. 50), if it amounts to a minute or more. Reference to a table of mean refractions ("Young's Manual of Astronomy," Table VIII) shows that 2′ is to be substracted from the first altitude, making it 27° 42′, but for the second no change is needed.

The section of a sheltered plumb line may serve as a gnomon, though the required measurements are not so readily effected.

OBSERVATION 2.—W. V. Lawrence, Kansas, Tuesday, March 19, 1912. To employ as a gnomon the plumb line near the south opening of the plumb-line booth (§ 9), a section is marked off by a bead fixed on the line a few inches below its supporting hook.

Since the floor of this temporary booth is somewhat uneven, a smooth, heavy plank, is laid down under the plumb lines and carefully levelled. White paper is pasted on the north end, and when the meridian line, marked upon it, bisects the shadow of the bead, a short line is drawn east and west through its center.

In this observation, the height of the "gnomon" is the distance from the centre of the bead to the point of the plumb bob, or rather, to the mark a few hundredths of an inch below it; and the length of its shadow is the distance from this mark to the east and west mark on the meridian line. The mean of several measures, for each, makes the former 52.64 in., the latter 43.12 in., and the sun's altitude derived, as usual, is 50° 40′.

44. Latitude from sun's noon altitude.—The main object in determining the altitude of the sun on the dates of the equinoxes and the solstices is to obtain data for finding latitude. For the sun's noon altitude at either equinox gives latitude, independently of declination (Byrd, § 115); and this is also true of the combined altitudes at the solstices, provided it is regarded as a known fact, that the sun, at these times, reaches points equally distant, north and south of the equator.

EXERCISE 1.—From the noon altitude of the sun at the solstices, derived in Obs. 1 of the preceding section, required to find the latitude of the given station.

Let SS' and SS'', in Fig. 8 (§ 27, Fig. 4), on page 51, represent the observed altitudes. The corresponding zenith distances are then $S'Z$ and $S''Z$, and their mean is equal to QZ, since, as just stated, $QS' = QS''$; but QZ is the declination of the zenith, which equals the latitude (§ 27). Therefore, half the sum of the sun's zenith distances, determined at noon on the days of the solstices, equals the latitude of the place.

If the numerical values for zenith distances are substituted, $S''Z = 62° 18'$, $S'Z = 15° 20'$ (§ 43, Obs. 1); and the mean of the two, 38° 49′, gives a value for the latitude of Wide View. As a check, it may be noted that the latitude of the State University, several miles east, but less than a mile north, is given as 38° 57′ (§ 87, Ex. 1).

The obliquity of the ecliptic QS' or QS'' (§ 15, *28*) derived from these zenith distances, is 23° 29′, showing a closeness of agreement with the Ephemeris value, 23° 27′, which is doubtless due in part to accident.

If the sun's declination is obtained from an almanac (§§ 25, 34), any noon altitude may be employed to find latitude.

Exercise 2.—From the sun's noon altitude for March 19, given in Obs. 2 of the preceding section, find the latitude of Wide View.

Since this is the day before the spring equinox, the sun is just a little below Q, Figure 8, say at S_1. Its zenith distance is then, $S_1 Z$, its declination QS_1, and the difference in the two gives QZ, the declination of the zenith, or the latitude required. The numerical reduction may be arranged thus:

Sun's observed altitude,	50°	40′
Correction for refraction,		1
Corrected altitude,	50	39
Sun's zenith distance,	39	21
Sun's decl. fr. p. 10, O. F. A.,		−30
Decl. of zenith or latitude,	38	51
True latitude of Wide View,	38	57
Error of observation,		6

The declination is so small that, if no account is taken of it, the latitude still comes within half a degree of the correct value. (§ 2, Ex. 25).

Another determination made a few days later in the same way, at the same place gave a latitude of 38° 55′. (See Ex. 3.)

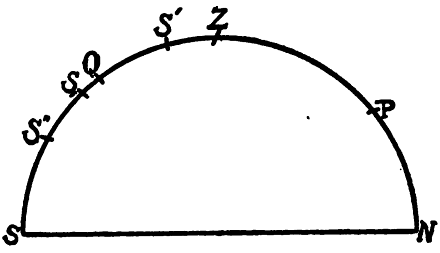

FIG. 8.

EXERCISE 3.—From the data given in the observation of § 31, find the latitude of Normal College, New York, N. Y.

Reference to the given section shows that on May 29, 1913, the sun was observed from the window gnomon, and its image bisected a little before noon. Measures made of the vertical distance from the center of the aperture to the south point of the meridian line, and the distance of the latter point to the center of the image, gave respectively, 20.00 in. and 6.94 in. (Fig. 6, § 31). If then, z is the sun's zenith distance,

$$\tan z = \frac{6.94}{20.00} \text{ and } z = 19° \; 8'.$$

Refraction, as it is less than half a minute is not included; and since for this date the declination of the sun is, +21° 36′, the declination of the zenith, that is the latitude of the place is, 19° 8′+21° 36′, *i. e.*, 40° 44′. As the true latitude of the college is 40° 46′ (Appendix), the error is 2′, an error which is, however, too small to be considered trustworthy, especially as the latitude derived, in like manner, on the same day by another observer was in error 12′.

Since south declinations are negative (§ 15, *23*), the general rule for finding latitude from the sun's zenith distance is, add algebraically to that distance, the sun's declination for the given date.

45. First observations of the moon.—Look first for the new moon the evening after it is set down as new in the almanac. Under favorable conditions, it is possible to see it then,* and the following evening it ought to be found, if the sky is clear.

After sunset has been observed, and its time and place noted approximately (§ 18), the search for the moon should begin. When it is first visible, record the time within a few minutes, note in what direction the horns point, what angle the line joining them makes with the horizon (Byrd, § 142), and whether the dark and illuminated parts seem to belong to the same circle. Watch the moon also at setting, entering in the notes the hour and minute, and locating the point where it disappears, either by sketching a small section of the horizon, or measuring azimuth or amplitude (§ 15, *12*, *13*). The observation should give data for describing the appearance known as the "old moon in the new moon's arms," for comparing the actual time of setting with the almanac time, and also the time and place of the setting of the sun and moon on the same date.

46. Moon placed in constellation.—To find out about the motion of the moon, it is necessary to locate it a number of times among the stars, so the question often to be answered is, "In what constellation is the moon tonight?" In fixing its place, depend directly upon the eyes, drawing imaginary star-lines, and estimating distances and angles, as in mapping a constellation (§ 33). It is, however, desirable to place the moon, or any moving body, at the end of one side of an angle, rather than at its vertex, *i. e.*, $\angle\,\alpha\gamma$ Ceti ☽ $=90°$ (§ 57, Obs.), not $\angle\,\delta$☽$\beta=90°$.

The main difficulty in locating the moon lies in the fact that its own light, as well as twilight, puts out the fainter stars, and obliterates the characteristic features of neighboring constellations, so that it is not easy to see and identify comparison stars. For the new moon it is helpful to become familiar beforehand with the appearance of the sky near the western horizon in the

* "Denning's Telescopic Work for Starlight Evenings," p. 136.

early evening (§ 41); but when this is impracticable, reference should be made to star-maps or the celestial globe, properly oriented (§ 40). A slow-moving bright planet which has been followed from week to week, and is known to be in the vicinity of certain stars, serves at times to fix the constellation; and it is always admissible to use opera-glasses, if the fact is stated (§ 17, *3*). When sunlight interferes, or clouds blot out all celestial objects except the moon, its place may be found by measuring its altitude and azimuth, and later plotting these coördinates on the celestial globe (§ 51, Ex. 1).

The location of the moon, when it is favorably placed, in line with two stars (§ 33) is illustrated as follows:

Observation.—84 Elm Street, Northampton, Mass. 7^h P. M., E. S. T., Wednesday, March 11, 1908. The moon is in line with α Orionis and γ Geminorum, and, if this star-line is prolonged upward $\frac{3}{4}$ of its own length, it reaches the moon. (A. E. T.)

From globe or map it is seen by mere inspection that the moon was in Gemini, and plotting fixes its place near the stars ζ and δ (§ 39, Ex. 1).

For a more critical location of the moon in reference to the stars see § 57, Ex.

47. **Moon's synodic period.**—This period is the interval from new moon to new moon, or from any phase to the same phase again. To determine its length, drawings may be made of the moon in different lunations. (See also Byrd, § 143).

Observation.—S. C. O., Northampton, Mass. In order to find the length of the synodic period, I have made this fall, 1911, five naked-eye sketches of the moon, outlining carefully the terminator and the markings visible. Later, comparison shows that those obtained Oct. 2nd and 30th are quite similar, though in the first, the terminator is slightly convex, while in the second, the moon appears just about half full. My next observation was on Nov. 2, and by noting the rate of change between that date and Oct. 30, I estimate that it would take 1.5 days for the moon to pass from the phase seen Oct. 30 to that of Nov. 2. The syno-

dic period required is, therefore, the interval between these dates, 28 days, plus 1.5 days or 29.5 days.

The same result is obtained by comparing, in like manner, the sketches of Nov. 2 and Dec. 4. The corresponding Ephemeris intervals are, $29^d\ 20^h$ and $29^d\ 11^h$. (H. P. O'M.)

48. Greenwich time changed to local or standard time, and *vice versa*.—These reductions are similar to those already described (§ 38), and the same principle applies, that is, the time of one meridian is expressed in that of another by making a correction for the difference in longitude between them. Since in our country all longitudes are reckoned west from Greenwich, the following precepts apply:

When Greenwich time is given, and local or standard time required, subtract from the former the difference in longitude between the two meridians employed; but add this difference to local or standard time in order to find the corresponding Greenwich time.

EXAMPLE.—Find the Greenwich time corresponding to $11^h\ 45^m$ A. M., local time at Salt Lake City; corresponding to $11^h\ 45^m$ A. M., standard time at Salt Lake City.

The longitude of this place is $7^h\ 28^m$ W. (Appendix), or, in other words, that is the difference in longitude between the meridians of Greenwich and Salt Lake City. It is, then, the interval of time to add to the given local time, $11^h\ 45^m$ A. M., to obtain the corresponding Greenwich time, $7^h\ 13^m$.

But the longitude of Salt Lake's standard meridian is 7^h W., so that number of hours added to the given standard time, $11^h\ 45^m$ A. M., gives $6^h\ 45^m$, as the Greenwich time required. Neither here nor above are the letters P. M. added, for Greenwich time is usually expressed as astronomical time (§ 35).

49. Sidereal time and right ascension of the meridian.—The instant when the vernal equinox (§ 15, *26*) crosses the local meridian, fixes sidereal noon, and its hour-angle at any moment is sidereal time. But this hour-angle equals the arc on the celestial

equator intercepted between the foot of the meridan and the vernal equinox (§ 15, *24*), an arc which also measures the right ascension of an object when it is on the meridian (§ 15, *29*). So it follows that the sidereal time of a star's meridian transit equals its right ascension.

Since it is customary to speak of the right ascension of the meridian, just as of an object on the meridian, its right ascension is said to be sidereal time; and when the globe is oriented for any position, the right ascension of the meridian, read at the graduated side of the meridian ring, is the sidereal time corresponding to that particular aspect of the globe (§ 40, Ex.).

50. **Interpolating between almanac values.**—Much of the astronomical data given in almanacs depends upon the element of time; and, for naked-eye observing, it is usually accurate enough to treat the required functions as varying directly with the time. The following exercises illustrate interpolations required in preceding or following sections:

Example 1.—Two consecutive times for the setting of Saturn, given in Jayne's Almanac, 1910, are,

Feb. 22,	9^h	30^m, P. M.
March 22,	7	57, P. M.

Required the approximate time of the planet's setting, Feb. 25.

The change in the time of setting is 93 minutes in 28 days, and so for the three days, between the 22d and 25th, the change is taken as $\frac{3}{28}$, *i. e.*, $\frac{1}{9}$, of 93^m or 10^m. Therefore, for Feb. 25, the almanac time of setting is $9^h\ 30^m—10^m$, or $9^h\ 20^m$ P. M. (§ 32, Obs.).

Example 2.—The right ascension and declination of the moon were determined by the unaided eye at Mantoloking, N. J., $3^h\ 35^m$ A. M., E. S. T., Tuesday, July 21, 1908 (§ 57, Obs.). Required the coördinates from the Ephemeris for this time.

Since the values sought are to be found in the Greenwich section of the Ephemeris (§ 34), the time of observation must first be expressed in the time used there. According to § 35, the

astronomical date is $15^h\ 35^m$, July 20, and by § 48, the Greenwich time is 5^h hours later or $20^h\ 35^m$, so the coördinates are to be taken out for a time $0^h.4$ before 21^h, as it is the rule in interpolating, to work always from the function nearest that required. The moon's right ascension and declination for 20 and 21 hours, from p. 118 of the Ephemeris are,

July 20, 20^h, ☽'s R. A., $2^h\ 30^m$; ☽'s Decl.,$+10°.2$
" " 21, ☽'s R. A., 2 32 ; ☽'s Decl.,$+10.4$

In one hour, therefore, the change in R. A. is 2^m, and in Decl., $0°.2$, and 0.4 of these differences subtracted from the values opposite 21^h, gives the required coördinates of the moon,

July 20, $20^h\ 35^m$, R. A., $2^h\ 31^m$; and Decl.,$+10°.3$

Exercise 3.—The following positions for Halley's Comet, 1910, are taken from Dr. Smart's Ephemeris, computed for 9^h Greenwich time. (Journal, British Ast. Ass., Vol. XX, No. 6):

May 23, R. A., $7^h\ 58^m.0$; Decl.,$+11°\ 40'$
May 24, R. A., 8 26 .4; Decl.,$+$ 9 33

Required the coördinates of the comet at $8^h.5$ P. M., C. S. T., May 23, 1910.

The time, $8^h.5$ P. M., for which the coördinates are desired, equals $14^h.5$, Greenwich time (§ 48), and so is $5^h.5$ later than that for which the Ephemeris is given. Since the change in right ascension in 24^h is $28^m.4$, and in Decl. $2°\ 7'$, $\frac{5.5}{24}$ of these differences are to be combined with the Ephemeris values for May 23, fixing the comet's place in,

R. A., $8^h\ 4^m.5$, and Decl.,$+11°\ 11'$.

When final results are to be carried only to the nearest minute of time and tenth of a degree of arc, a difference of several hours often makes no change in the Ephemeris value.

Exercise 4.—Find the right ascension and declination of Mercury for $8^h\ 4^m$, P. M., C. S. T., April 19, 1911, at a place in longitude $6^h\ 21^m$ W. and latitude $+39°.0$.

Washington time is first obtained as follows:

Central standard time,	8^h	4^m
Standard meridian east of place,		21
Local mean time,	7	43
Washington east of place,	1	13
Washington time of observation,	8	56

Since the Washington time for which the coördinates of the planet are given is $1^h\,8^m$, it follows that $8^h\,56^m - 1^h\,8^m$ or $7^h\,48^m$ is the interval to be used in making the interpolation. During 24 hours, the changes in coördinates are, $1^m.9$ in right ascension and $7'$ in declination, so the corrections required are $\frac{7.8}{24}$ or $\frac{1}{3}$ of these differences, making right ascension $2^h\,55^m.2$ and declination $19°\,47'$, values, which if taken only to the nearest minute, and tenth of a degree are the same as those given directly in the Ephemeris (§ 17, *9*).

After some practice, interpolations like those above are to be made wholly, or in large part mentally.

51. Plotting on the celestial globe.—In general, plotting on the globe closely resembles that done on star-maps (§ 39). There are, however, differences in detail, and where the object considered is referred to the horizon, it is practicable to use the globe only.

Exercise 1.—The coördinates of a body thought to be Mercury were measured with jointed-rods and protractor, at $8^h\,4^m$, P. M., C. S. T., April 19, 1911, in longitude $6^h\,21^m$ W., latitude, $+39°$. The altitude obtained was $5°.5$, azimuth $112°.5$ required to locate the body among the stars and find out whether or not it was Mercury.

It should be added that according to the original notes, the observation was made under difficulties, for no meridian line was available, and the west point was taken roughly by aligning

from the frame of a west window. However, no other object in the vicinity was nearly as bright.

In order to locate the body on the globe, orient it for latitude and time (§ 40), and see that it is held firmly in position (§ 29). Then mark off the observed altitude 5°.5, near one end of a narrow strip of paper, which serves as a vertical circle. Pass the other end through the zenith point of the globe (§ 27), bringing the lower mark for altitude to coincide with the given azimuth, 112°.5, as read on the horizon plate, and the upper mark for altitude fixes the place of the body observed. This point is marked by a dot on a bit of paper, moistened and pressed on the globe. It is found to be in the constellation Aries, near the fifth magnitude star ϵ. To obtain its coördinates referred to the equator, one method is as follows (Ex. 3): Unclamp the globe, turn it till the marked point comes to the graduated side of the meridian ring, and the number of degrees opposite, 21°.3, gives the required declination; and the corresponding right ascension is the time, $2^h\ 51^m$, read from the equator where it intersects the ring.

Since the values taken from the Ephemeris are R. A., $2^h\ 55^m$ and Decl. +19°.8 (§ 50, Ex. 4), the two sets of coördinates, taken in connection with the statement about brightness, show an agreement close enough to warrant the conclusion that the body observed was Mercury.

The converse of this problem arises when right ascension and declination are known, and it is required to find altitude and azimuth, either to check observed values, or to make a setting with the altazimuth instrument so as to pick up quickly a faint object. As an illustration, the data given in connection with the preceding exercise may be taken in reverse order.

EXERCISE 2.—The right ascension and declination of Mercury for the evening of April 19, 1911 are, $2^h\ 55^m$ and, +19°.8, respectively, (§ 50, Ex. 4) find its altitude and azimuth for the time and place of Exercise 1.

Here the first step is to locate Mercury. Turn the globe, therefore, till the given right ascension, read on the equator, comes to

the graduated side of the meridian ring, look along its edge for the number of degrees in the declination, and just opposite is the place for the planet, which is marked as in Exercise 1.

To obtain its coördinates referred to the horizon, orient the globe for time and place of observing, clamp it in position, and pass a strip of paper through the zenith point of the globe, and that fixed for Mercury. Where it intersects the horizon plate, the reading for azimuth, 110°.8 is that required, and the intercept between the planet and the plate, 4°.6 is the corresponding altitude.

It is evident that either one of these exercises gives an identification of the body observed, and that is the main object of such plotting, especially as values of altitude and azimuth which cannot be checked from declination, or readily from the globe (§§ 28, 29), are usually tested adequately by plotting on rectangular paper (§ 80).

A more common form of plotting is employed in verifying or correcting the star places, and dots for the sun (§ 26), which are marked on the globe.

EXERCISE 3.—In reducing the observation of Venus and Mars when in conjunction (§ 60), the star-line $\delta\epsilon$ Orionis, measured, on the globe, was found to differ a third of a degree from the length derived by calculation. Required to plot these stars on the globe and find the distance between the places thus obtained.

The coördinates of δ Orionis, taken from mean-star places in the Ephemeris for 1908 (§ 34), are R. A., $5^h\ 27^m.3$, and Decl., —0°.37. To fix its place as accurately as possible it is better, instead of using the meridian ring of the globe (Ex. 1) to work directly from the nearest reference circles, as on star-maps (§ 39). Since, however, there are on the globe no intermediate circles between those for whole hours, and 10°–spaces, $27^m.3$ and 0°.37 must be expressed in linear measure. On the equator, near which the stars are situated, it is seen that $60^m = 52.4$d, d standing for a division of rectangular paper used, and 10° in declination equals 35.0d. Therefore, $27^m.3 = \frac{27.3}{60}$ of 52.4d, or 23.8d, and $0°.37 = .37$ of 3.5d or 1.3d; and the point for the star

is marked 23.8d east of the 5^h–circle and 1.3d south of the equator. In like manner ϵ Orionis is located and the space between them, 5.0d, on the basis of 105d to 30° equals 1°.4, a value agreeing with that obtained by trigonometry (Byrd, § 72).

Here, as usual in numerical calculations, the preliminary work is carried further than final results, *i. e.*, one tenth of a division of the paper is less than a tenth of a degree.

By far the largest number of exercises which require plotting on the globe are connected with direct observation of position for moon, planets, and comets, where the data given are estimates of distance, and angular direction from neighboring stars.

EXERCISE 4.—Pasadena, Calif., $4^h.3$ A. M., P. S. T., Saturday, September 7, 1907. The position of Daniel's Comet was fixed among the stars by the following estimates (§ 72, Obs. 2):

Position 1—$\angle\beta\alpha$ Cancri ☄ = 175, α Cancri ☄ = $\frac{3}{4}$ $\alpha\beta$ Cancri.

Position 2—$\angle\zeta$ Hydræ α Cancri ☄ = 95°, α Cancri ☄ = $1\frac{1}{2}$ α Cancri ζ Hydræ.

Required to locate the comet on the globe and find its right ascension and declination.

Adjust the globe and secure it in position with the constellations Cancer and Hydra in convenient position. Cut out, with the help of a protractor (§ 11), the paper forms for the angles, and proceed thus with the first set of estimates.

Place the vertex of the angular form for 175° on the star, α Cancri, with one side passing through β Cancri, and the other extending indefinitely in the direction of the comet, as shown by Fig. 10, § 72. Then, on the latter side, lay off $\frac{3}{4}$ $\alpha\beta$, and the point marking the end of that space fixes the first position of the comet. The second is found in like manner, and as the observer's notes contain nothing about unequal weighting (Byrd, § 4), the point midway between the two is taken as the observed place for the comet.

To derive the coördinates of this point in reference to the equator, it is to be noted that 51.0d equals 60^m on this part of the globe, and that 35.3d equals 10° of declination. Then, as the dot for the comet is found to be 23.0d east of the 9^h–circle, and

11.7d north of 10°–parallel, north, the corrections to be added to the values read directly are, $\frac{28}{61}$ of 60^m or 27^m; and $\frac{11.7}{35.3}$ of 10° or 3°.3, making the required right ascension, $9^h\ 27^m$, and declination, +13°.3.

The telescopic position fixed at Vienna, corresponding to the time of this observation and carried only to the same limits is, R. A., $9^m\ 27^s$ and Decl., +11°.9 (§ 72).

When a series of observations is to be plotted, paper that is simply moistened is unsatisfactory, as the pieces are likely to drop off before the work is finished. For such exercises, it is well to prepare beforehand narrow strips of paper, like the margins of a newspaper, by spreading on them a very thin layer of photographer's paste and allowing it to dry. Plotting is also facilitated, if all angular forms required are cut out beforehand, coördinate paper being preferably used for the purpose.

To mark out a path graphically, after locating a number of points, fine, flexible wire, small cord, or coarse thread, well waxed are serviceable, and bits of paper, like that just mentioned, may be used to hold any one of them in place while tests and comparisons are being made. (§ 57, Obs.).

52. **First tests of opera-glasses.**—A good pair of opera-glasses, when pointed at the moon, for example, gives one field of view, one image and no fringes of light. If, however, in looking at the sky, two circles of light appear, either distinct or overlapping, the glasses have the defect of double field of view. It is not uncommon and interferes little with their use, but if two images of a single object are seen, the instrument is worthless. Conspicuous fringes of light about a bright object are also objectionable, but a little extraneous light does no harm.

In finding the diameter of the object-glasses, it will not do to lay anything, even a strip of paper, on the glass itself. Instead, place a finely graduated scale on the top of the cell, as nearly over the center as possible, and align downward by the eye. The mean of three diameters read thus is accurate enough for all practical purposes.

53. Preliminary exercises with a telescope.—A telescope should be used first in the daytime, when the essential parts and the connection between them can be plainly seen. This is the time to practice making the different motions and adjustments, to focus on a distant terrestrial object and ascertain how the instrument inverts, that is, whether the image is turned partially, as in a mirror, or whether it is completely inverted, both up for down and right for left.

In focusing either telescope or opera-glasses, pains must be taken to obtain sharp, clear-cut images. Never be satisfied with motion in one direction, but push the eye-piece in and draw it out, till the point of most distinct vision is passed in opposite directions, and then a quick motion or two should give that point.

For the first evening exercise three things are important, to repeat with a bright body, the moon if possible, the observations already made on a terrestrial object, to find in what direction heavenly bodies cross the field of view, and to determine how the telescope, when carefully focused, affects the size and brightness of stars and planets.

In handling a telescope, it is hardly possible to exercise too much care. Hasty, rough motions, pushing hard, or jamming any of the parts are reckoned among the deadly sins of an astronomer.

54. Light-gathering power of a telescope.—A telescope brings to the eye far more light than falls directly on the pupil, for that has a diameter of only about 0.2 of an inch, and the light received on different circles varies as the square of their diameters. If then, the diameter of an object-glass is 2 inches, and L and L' represent the quantity of light falling respectively on the eye and on the objective, their relative amounts are given by the proportion,

$$L : L' :: (0.2)^2 : (2.0)^2 \therefore\ 4\,L = .04\,L' \text{ and } L' = 100\,L.$$

Since, however, even with a small telescope, nearly $\frac{1}{5}$ of the light is lost in passing through the lenses, a telescope with a 2-inch objective brings to the eye about 80 times as much light as it receives directly.

CHAPTER V.

First Observations with Opera-glasses; Lunar Paths; Moon's Sidereal Period; Location of Planets; Time from Sun and Stars; Sidereal Day; Sidereal and Mean Solar Time; Further Tests for Opera-glasses and Small Telescope.

55. **Sun, moon, and planets with opera-glasses.**—The most brilliant heavenly bodies are not the ones most satisfactorily examined with opera-glasses. An average pair, magnifying two or three diameters, shows no disk even for Jupiter or Venus, and little is practicable with any planet except to note the effect of the glasses on color and brightness (Byrd, § 173). For the sun also, observations are mainly limited to points like these. At first let an examination be carefully made with dark spectacles only, and then see how opera-glasses affect color, size, and brightness. Note whether the limb is ill-defined, or sharp and clear cut, how it compares in brightness with the center; and whether the whole body appears like a disk laid on the sky or like a true sphere. If, as occasionally happens, there is a sun spot large enough to be visible, fix its position by a dot marked on a circle, representing the solar disk.

With the moon rather more is possible. In addition to points like those above, see whether the glasses appear to have any effect upon the direction and rapidity of the moon's apparent motion, what part of the field of view (§ 67) is occupied by the full moon, and whether the terminator appears more or less irregular than with the naked eye. Different phases should be examined, and sketches made of the same phase in different lunations, so as to find out whether the markings change their position with regard to limb or terminator (Byrd, § 132). As many as seven of the "seas" should be identified with the help of a lunar map.

In recording, enter the age of the moon as well as the hour of observing. Bear in mind also that when opera-glasses are

first used with any object, emphasis must be placed on obtaining the best possible focus before anything else is attempted (§ 53).

56. Moon's diurnal path with and without instruments.—There are various ways to locate points in the diurnal path of the moon. If the meridian and horizon are taken as reference lines, only a few minutes at the beginning and end of the evening period are required for notes like these: "At 7^h P. M., the moon is not very high and about midway between the meridian and the western horizon; At 9^h P. M., it is near the distant tree tops to the southwest." If the altitude is not too large, a sketch may be made of that part of the horizon in the vicinity of the moon, and its place fixed more than once in the evening by reference to trees and buildings, care being taken to observe each time from exactly the same place.

More accurate data are obtained by making estimates or measures. Thus, altitude can be expressed in terms of the altitude of a star or planet, and azimuth or amplitude as a part of the quadrant between two cardinal points. Measures are made most conveniently with an altazimuth instrument, as in finding the diurnal path of the sun (§ 30). But the intervals may well be shorter, and the points fixed fewer in number, including usually only one of the three critical points, rising, southing, and setting. Any one of these points gives the key to the moon's path for the day (§ 80), but special interest attaches to places of rising and setting. If for either, several points are fixed for different phases in one season, or for the same phase in different seasons, striking contrasts are brought out (Byrd, §§ 139, 140).

57. Path of the moon among the stars.—When as many as five positions of the moon have been fixed in one lunation (§ 46), they should be plotted on the celestial globe. They ought to give data for determining the direction and rate of the moon's motion, and its path through several constellations. If it is practicable to obtain ten or more positions, as in the following illustration, other important deductions can be drawn.

Observation.—During July and August 1908, I followed the course of the moon through an entire lunation, beginning when it was three days old, July first, and continuing observations till after new moon in August. Positions were fixed on 15 dates, but owing to an unbroken series of cloudy nights, the latter part of July, they were not so well distributed as is desirable. All

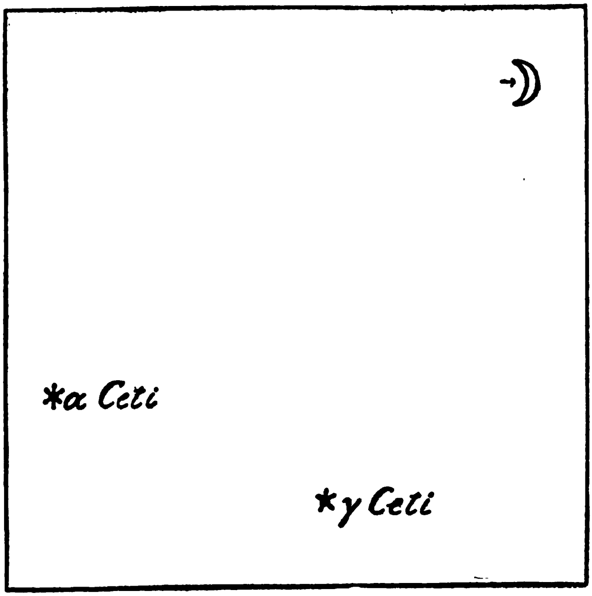

Fig. 9.—Moon in Reference to Stars.

were based on definite numerical estimates, like those given below for July 21, and the sketch added (Fig. 9) shows how the moon was placed in reference to the stars employed on that night.

Mantoloking, N. J., $3^h\,35^m$ A. M., E. S. T., Tuesday, July 21, 1908. The moon is east of Aries, and I estimate,

$\angle\,\alpha\gamma$ Ceti ☽ $=90°$; γ Ceti ☽ $=1\frac{3}{4}\ \alpha\,\gamma$ Ceti.

Another estimate gives, γ Ceti ☽ $=1\frac{1}{2}\ \alpha\,\gamma$ Ceti.

(J. T. V.)

Not only as here, is it well to note two distances in locating a heavenly body; but to make, when practicable, two completely independent estimates of position, and so lessen the effect of accidental errors (Byrd, § 3).

To reduce and discuss a series of observations like those taken at Mantoloking, they should be plotted on the celestial globe. A number of details are involved, and these are most readily explained by describing the work actually carried out for this series.

EXERCISE.—From the data given above, for the moon on July 21, 1908, fix its place on the globe, and find its coördinates in right ascension and declination.

After the globe is adjusted and secured in position with the stars employed conveniently placed, a rectangular piece of plotting paper is used in locating the moon (§ 51, Ex. 4). Let one of the right angles be placed on the star, γ Ceti, one of its adjacent sides pass through α Ceti, and the other extend northward, as indicated in Fig. 9. The moon's exact position on this side is fixed by laying off from γ the mean of the two estimated distances between it, and the star.

To find the right ascension and declination of the point thus determined, note that in its vicinity, 51.3d, on the rectangular paper used, equals 60^m, and 35.5d equals $10°$ of declination. Therefore, as the place for the moon is 24.7d east of the 2^h-circle, and 1.0d north of the $10°$-parallel, north, it follows that the entire right ascension and declination are, $2^h\,29^m$ and, $+10°.3$. The values of these coördinates obtained by interpolating from the Ephemeris are, $2^h\,31^m, +10°.3$ (§ 50, Ex. 2).

In like manner, all the fifteen positions are plotted on the celestial globe, and a coarse thread, placed as symmetrically as possible in regard to them (Byrd, § 207, Fig. 33) marks out the path of the moon. The thread, stiff with wax, is held in place by narrow strips of adhesive paper (§ 51), so that the globe can be turned back and forth and the path examined throughout its course of 360°.

It is found to lie within the zodiacal constellations, except that at one point it passes over the boundary line of Aries into

Cetus, and enters Ophiuchus for a few degrees, where that constellation extends on both sides of the ecliptic. Its farthest distance north of this circle is 3°.5, farthest south, 5°.5; and as about half of it is above and half below the ecliptic, it is fair to conclude that the moon's path through the stars is approximately a great circle, lying near the ecliptic, and inclined to it by an angle not differing much from 5°.

A check for the whole path is obtained by taking the moon's right ascension and declination from the Ephemeris for the times of observation, plotting them on the globe and marking the corresponding path, as described above. Comparison of the two, shows that the path laid down from naked-eye estimates coincides in places with that derived from the Ephemeris, is not often 1°.5 from it and never quite 2°. It should be added, however, that this check does not bring out clearly errors in right ascension.

Instead of plotting individual positions, four critical points suffice for an approximate check. Thus, the intersections of the moon's path with the ecliptic, that is, its nodes (Young, Art. 142) are located from the longitude of the nodes (§ 34); and the points in the path farthest north and south are fixed, 5° above and 5° below the ecliptic, just 90° from each intersection. A small cord, or fine, flexible wire passed through the four points marks out the required path.

58. Moon's rate of motion and sidereal period.—Any two positions of the moon, if they are fairly accurate and several days apart, give satisfactory data for determining its rate of motion. Take, for example, the observations of July 5 and 10, in the series discussed in the preceding section. The arc between the corresponding positions plotted on the celestial globe is 66°.0 in length, and this divided by 5, the number of days intervening, shows that the moon was traveling at the rate of 13°.2 a day or 0°.55 an hour. In like manner, from the observations of July 8 and 13, the rates per day and hour are found to be, 12°.9 and 0°.54. The mean daily rate given by Young, Art. 141, is 13° 11″ which makes the hourly rate 0°.55.

The sidereal period of the moon is the time it takes to make a complete circuit of the celestial sphere, that is, to pass from a particular star back to the same star again. Its length can be determined from the data of § 57; for the plotted path there described shows that, on Aug. 4, the moon had nearly but not quite reached the position occupied July 8, 27 days earlier. The intervening space measures 3°.3, and to traverse it, the moon requires 6.6 hours, as it moves practically over half a degree in an hour. The interval between the given dates, carried to hours, is $26^d\ 23^h.4$ and the $6^h.6$ added makes the whole sidereal period $27^d\ 6^h$.

Another value for this period is obtained in like manner by comparing the observations of July 6, and Aug. 3. On the latter date, however, the moon had gone beyond the position of July 6, a space equal to 7°, so 14 hours is to be subtracted from the interval between these observations, making the required sidereal period $27^d\ 9^h$.

The numerical work required is, in brief, as follows:

Time of Obs., July,	8^d	9^h	0^m	Time of Obs., July,	6^d	9^h	40^m
" " " , Aug.,	4	8	25	" " " , Aug.,	3	8	38
Int. bet. the two,	26	23.4		Int. bet. the two,	27	23	
T. for ☽ to go 3°.3,		6.6		T. for ☽ to go 7°,		14	
Sidereal Period,	27	6			27	9	

Young, Art. 141, gives $27^d\ 7^h.7$ as the average period.

59. **Planets mapped in reference to stars.**—The study of planetary motion is based upon fixing at a definite time an accurate position of a planet among the stars. This is effected just as in mapping the moon, except that stars can be employed which are fainter and nearer the body observed.

The following examples illustrate the location of single points, and it is only necessary to obtain a number in order to trace the path of a planet through the constellations (§ 83).

OBSERVATION 1.—W. V. Lawrence, Kan., Tuesday, Sept. 3, 1907. Between eight and nine this evening, Mars occupies an unusually favorable position; for it is almost exactly at the intersection of two star-lines, $o\ \zeta$ and $\tau\ \phi$, *i. e.*, the diagonals of the bowl of the "milk dipper" in Sagittarius.

OBSERVATION 2.—84 Elm Street, Northampton, Mass., 8^h P. M., E. S. T., Monday, March 16, 1908. It is the night before full moon, and faint stars cannot be seen in mapping Jupiter. As usual I make a rough sketch showing how the planet is placed among the stars, as well as the following numerical estimates of distance and angle:

Position I.— $\angle\ \beta$ Gem. ♃ α Can. Min. $= 90°$

β Gem. ♃ $= \frac{4}{5}\ \alpha$ Can. Min. ♃ $= 3\ \alpha\ \beta$ Gem.

Position II.— $\angle\ \gamma\ \alpha$ Gem. ♃ $= 90°$; α Gem. ♃ $= \frac{3}{4}\ \alpha\ \gamma$ Gem.

(A. E. T.)

To find where these planets were situated on the celestial sphere at the times of observation, there is no better method than plotting on the celestial globe, as in § 57. When, as above for Jupiter, two places are fixed, the final observed position is to be taken just midway between the two points plotted, though if preferred, the coördinates of each point may be read and the mean taken. Corrections for precession require little extra labor (Byrd, § 57), and are properly included, as in the following table, which contains the final right ascensions and declinations of both planets.

TABLE IV.—POSITION OF ♂, SEPT. 3, '07. POSITION OF ♃, MAR. 16, '08.

	FR. OBS. AND GLOBE.	FR. EPHEM.	FR. OBS. AND GLOBE.	FR. EPHEM.
R. A.,	$18^h\ 48^m$		$8^h\ 16^m$	
Corr. for Prec.,	+ 2		+2	
Corrected R. A.,	18 50	$18^h\ 51^m$	8 18	$8^h\ 26^m$
Decl.,	$-27°.9$		$+20°.9$	
Corr. for Prec.,	+ 0.1		− 0 .1	
Corrected Decl.,	−27 .8	$-27°.5$	+20 .8	$+20°.1$

To facilitate comparison, the coördinates from the Ephemeris are inserted opposite the corrected values, derived from observation.

60. Conjunction of planets.—When one bright planet passes another, the points to be noted are, their relative positions, and the distance between them at the time of conjunction, though this is not necessarily the smallest distance; for conjunction signifies merely that heavenly bodies have the same longitude or right ascension. The time to observe is on the date of conjunction given in the small almanacs, and, if clouds permit, it is well to include also the night before and the one following.

OBSERVATION.—Ridgmont, Greenfield, Mass., 8^h P. M., E. S. T., Friday, April 3, 1908. In the west, not far above the horizon, Venus and Mars are seen near together, Venus being a little higher and to the east of Mars. I estimate that the distance between them is just equal to that separating two of the stars in the belt of Orion, that is,

Distance bet. ♀ and ♂ $= \delta\ \epsilon$ Orionis.

The following evening, April 4, is the almanac date of conjunction, and from the same place at 8^h P. M., I look again at the planets. There is only a slight change in position, I estimate,

Dist. bet. ♀ and ♂ $= \frac{9}{8}\ \delta\ \epsilon$ Orionis.

Owing to clouds, no observation could be taken on the third night. (B. F. F.)

The distance measured on the globe between the plotted positions of δ and ϵ Orionis is $1^\circ.4$ (§ 51, Ex. 3), and calculation gives the same value (Byrd, § 72). Therefore, according to observation, these planets were separated by $1^\circ.4$ at 8^h P. M., April 3, and at the same hour, April 4, by $1^\circ.6$, giving a mean distance of $1^\circ.5$ at the mean of the astronomical times of observing, April $3^d\ 20^h$ (§ 35). Reference to the Ephemeris which, of course, was not consulted beforehand by the observer, shows that the actual time of conjunction was April $3^d\ 22^h$, and that Venus was then $1^\circ\ 37'$ north of Mars.

61. Time and meridian line from the gnomon.—If the common form of gnomon is employed, it must be carefully adjusted, especially is it essential that the east edge of the upright should be vertical to the meridian line (Byrd, § 112, Obs. 3). To bring the shadow out sharply, paste strips of white paper over a large part of the line, leaving, however, a small section near each end, so that with a ruler the whole line can be drawn on the paper.

Preparations should be completed a few minutes before sun noon, in order that the observer may give undivided attention to the moving shadow. When it coincides with the meridian line, the word "time" or better, "tip" is called, and the recorder notes the second, minute, and hour. If the time-piece is set to standard time, its error is found as described a little later in this section.

The converse of this observation lies in marking a north and south line, when the time of sun noon is known. Let the line already drawn be entirely covered with paper to prevent any bias in its favor, and the observer be in readiness a little before noon. At the signal for this instant, two marks should be made quickly, the first at the edge of the shadow well to the north, and the second near the gnomon. In both exercises the edge of the shadow is to be taken about midway between the umbra and the penumbra (§ 43).

The following determination of watch error illustrates the use of the solar-image gnomon:

OBSERVATION.—N. C., New York, N. Y., Monday, June 9, 1913. To find time, I employ the gnomon described in § 31, taking note of the sun's image formed by the single aperture over meridian line No. I, reckoned from the east. As this image approaches the meridian, I watch it closely and call "tip" when it seems bisected. A little later as the image still appears to be bisected, I call "tip" a second time. The record obtained is,

$$\left.\begin{array}{r} 11^h\,55^m\,44^s \\ 49 \end{array}\right\}\begin{array}{l} \text{Rec. B. G.} \\ \text{Watch, Ingersoll No. 2.} \qquad \text{(E. B.).} \end{array}$$

Since the watch employed was set to eastern standard time, the reduction of the observation consists in finding, from this

standard time of apparent noon, how many seconds the watch was fast or slow. If the rigorously correct time of apparent noon were known, the difference between that and the observed time would give at once the error sought. But this "rigorously correct time" is simply apparent time converted to standard time, an operation which requires only two steps, the change of apparent noon to the corresponding local mean time, and that in turn to standard time (§ 38, Ex. 5).

In concise form the reduction is as follows:

Sun noon, apparent time,	$12^h\ 00^m\ 00^s$
Equation of time,	−1 3
Local mean time of sun noon,	11 58 57
Stand. Merid. west of New York,	4 9
Stand. time of sun noon fr. calculation,	11 54 48
Stand. time of sun noon fr. observation,	11 55 46
Watch fast by this observation,	58

The true error of the watch was obtained by comparing it by telephone with the standard clock of the Western Union Time Service, and was found to be $1^m\ 10^s$ fast, making the error of observation 12^s.

62. Time from meridian transit of sun or stars.—The fall and winter when the sun runs low are favorable seasons for determining time from the sun's noon transit over plumb lines. These may be supported and adjusted in different ways, but it is desirable to have them under shelter.

Observation 1.—W. V., Lawrence, Kan., Saturday, Nov. 25, 1911. The plumb-line booth, used in observing the sun's transit today, is like that described in § 9. The two plumb lines, which fix the meridian, owing to the sun's low declination, are satisfactorily placed three feet apart, the one at the north being hardly a third as thick as that near the south opening.

Nine times are noted, that is, the transit of west limb, center, and east limb over each of three pair of lines. These are designated in the record as west, central, and east pair.

STANDARD TIMES OF SUN'S TRANSIT.

West Pair—West limb,		12^h	1^m	20^s
	Center,		2	40
	East limb,		4	0
	Mean,		2	40
Central Pair—West limb,			6	8
	Center,		7	44
	East limb,		9	20
	Mean,		7	44
East Pair—West limb,			10	58
	Center,		12	40
	East limb,		14	8
	Mean,		12	35
	Final mean,	12	7	40

Since the true time of transit, found as in the preceding section, is $12^h\ 8^m\ 5^s$, the combined error of watch and observation is, $+25^s$; but comparison with jeweler's time, makes the watch slow 17^s, and so according to this test, the error of observation is 8^s.

A week later, another observation of the sun, made and tested in like manner was found to be in error 2^s (Obs. 2).

Astronomers invariably obtain accurate time, not from the sun, but from the stars, that is, they find directly the error of a sidereal clock or chronometer. Beginners also may employ a similar method, for any watch serves as a sidereal time-piece, if two changes are made. It should be regulated to gain about four minutes a day on mean time, and the hands set forward or

backward to mark sidereal time (§ 64, Ex.). Indeed, the latter correction alone suffices, when the period of observation is short.

OBSERVATION 2.—W. V., Lawrence, Kan., Saturday, March 16, 1912. The transit of Sirius is taken from the plumb-line booth used in observation 1, but the upper part of the south aperture is left entirely open, and the lines, the same as for the sun at this season, are separated by two feet. They are all satisfactorily lighted by a single, small, kerosene lantern; and, when adjustments are made, the one at the south shows as a narrow white band, and those at the north, when properly projected, as black lines through its center.

The following record is made from an Elgin watch, set to sidereal time, where for each pair of lines two times are noted (Obs. 1), the first, as soon as the star seems bisected, and the second when, if anything, that instant is passed.

SIDEREAL TIMES OF THE TRANSIT OF SIRIUS.

West Pair,	6^h	33^m	45^s
		34	12
Mean,		33	58
Central Pair,		40	38
		41	8
Mean,		40	53
East Pair,		47	10
			40
Mean,		47	25
Final mean, obs. time of transit,	6	40	45
Ephem. R. A., sid. T. of transit,	6	41	16
Watch slow by observation,			31

According to jeweler's time, the correct error of the watch was, +32, making the error of observation 1^s, too small an error, however, to be considered trustworthy in naked-eye observing.

63. Sidereal day from star transits.—A sidereal day is the interval between two successive transits of the same star across the meridian. Its length is usually given by comparing it with the mean solar day, which is the interval between two sucessive transits of the sun over the meridian. The latter may also be defined as any period of 24 hours, marked off by a clock or watch keeping mean time, provided there is, meanwhile, neither gain nor loss.

The comparison between the two days is effected by observing the transit of a star on one night, and the transit of the same star over the same reference line on the following night, a mean-time watch being used in recording. Assume for a moment that the observations are perfect, and that the watch keeps perfect time, then the three possible relations between the days are stated thus:

If the second transit of the star comes at the same time as the first, the days are equal; if later, the sidereal day is the longer; if earlier, the sidereal day is shorter than the mean solar day. In dealing with actual observations, watch errors must be taken into account, and it is desirable to have an interval of a week or more between the transits so as to reduce the effect of errors in observing.

Observation.—S. C. O., Northampton, Mass., Oct., 1905. During this month the transit of the star Fomalhaut was observed twice over the same plumb lines which remained fixed in position (§ 8). The times of transit, taken from a mean-time watch, were, $8^h\ 39^m\ 40^s$ and $8^h\ 12^m\ 10^s$, the watch being slow 41^s on the first night and 29^s on the second. The observed times, therefore, corrected for watch errors make,

Fomalhaut's time of transit, Oct. 9,	$8^h\ 40^m\ 21^s$
" " " " " 16,	8 12 39
Second time of transit earlier than first,	27 42
	(S. S.)

Since, after an interval of 7 days, the star crossed the reference line nearly 28 minutes earlier than at first, after one day's in-

terval, it would cross about 4 minutes earlier. The calculation carried to seconds makes the sidereal day shorter than the mean solar by $3^m\ 57^s$, a second larger than the true value, $3^m\ 55^s.9$ (Comstock's Field Ast. 19 (19)). In exercises like this, where the difference between observations is taken, an error of one second is a more satisfactory test of accuracy than for a single determination of time (§ 62, Obs. 2).

A moment's consideration shows that this gain of sidereal time is, in reality, a measure of the sun's apparent motion. Thus, assume that the sun and reference star cross the plumb lines at the same instant on a given day, on that following, the sun will cross nearly four minutes later than the star; and, as the star is practically a fixed point, the difference in the time of transit, $3^m\ 57^s$, according to this observation, is the daily rate at which the sun appears to move eastward among the stars.

Furthermore, if it be taken as a known fact that this motion of the sun is nearly uniform in a great circle of the sphere, the length of the year may be ascertained approximately. For 360° or 24 sidereal hours, divided by the sidereal gain in one day, gives the number of days required for the sun to pass from a given position in regard to the stars back to the same position again; and this is by definition a year (Young, Art.133). The daily gain found above by observing Fomalhaut is in mean time, reduced to sidereal by Table III of the Ephemeris, it becomes $3^m\ 57^s.6$ (*i. e.*, 0°.99, see § 41, Obs.), and 24^h divided by this interval makes the length of the year 363.6 days.

A more trustworthy, and probably more accurate result, would be obtained by taking the mean of a large number of observations, though here the watch errors have been determined more accurately perhaps than in many instances.

64. Relation between sidereal and mean solar time.—According to the preceding section, sidereal time gains $3^m\ 57^s$ ($3^m.95$) a day on mean solar time or about 10^s an hour. This rate is usually accurate enough for reducing hours and minutes in either time to the corresponding interval in the other; but, if

desired, exact corrections can be taken from the Ephemeris, Tables II and III. When, instead of dealing with intervals of time, it is required to convert the time of day from mean solar to sidereal time, or *vice versa*, the operations involved are more complicated (Byrd, §§ 51–53). It is not difficult, however, to make an approximate reduction, since sun and star time agree at the vernal equinox and at the autumnal, differ by 12 hours.

EXAMPLE.—After Nov. 6, 1909, the right ascension of Polaris to the nearest minute is $1^h\ 27^m$ for the remainder of the month (Ephemeris, p. 322). What, approximately, is its mean time of meridian transit, Nov. 12, 1909?

Since a star's right ascension is its sidereal time of meridian passage (§ 49), the requirement is really to reduce a given sidereal to mean solar time. Two corrections must be applied, one, the difference at the autumnal equinox, between sidereal and mean solar time; the other, the gain of sidereal on mean solar time during the interval of 50 days between the equinox and the given date, Nov. 12. The whole of the former correction is $12^h\ 8^m$ (Jayne's Almanac, p. 19), and the latter is $3^m.95 \times 50$, or $3^h\ 17^m.5$. The two combined equal $15^h\ 26^m$, which subtracted from the sidereal time, $1^h\ 27^m$, gives $10^h\ 1^m$. By the rigorous solution $10^h\ 0^m$ is obtained (§ 38, Ex. 4), and in Jayne's Almanac this is the time given.

65. Times, at different meridians, for the moon's phases.—The instant of any phase of the moon depends upon the relative positions of sun, earth, and moon, and is in nowise affected by the location of the observer. One determination of time, therefore, suffices and if that is made for Greenwich, the time of any other place is found by reducing Greenwich time to that of the given meridian (§ 48).

EXAMPLE.—Required to find what day, hour, and minute should be given in Jayne's Almanac for first quarter of the moon in Oct. 1908.

Since this almanac is calculated for the meridian 5 hours west of Greenwich, that is the interval to subtract from the Green-

wich time of the phase, $2^d\ 18^h\ 14^m$ (Ephemeris, p. 175), to obtain the almanac time, which is $2^d\ 13^h\ 14^m$, or in civil reckoning, Oct. $3^d\ 1^h\ 14^m$ A. M. (§ 35), and this is the time given in Jayne's Almanac, p. 21.

Washington instead of Greenwich times may be taken from the Ephemeris, but more changes of sign are involved, if all sections of the country are considered.

66. Times of the phases of a lunar eclipse.—Any phase of a lunar eclipse, like the phase of the moon, occurs at one and the same absolute instant of time wherever observed. It follows, then, that Greenwich time being given, any local or standard time required is obtained as in § 65 by reducing Greenwich time to that of the given meridian.

EXAMPLE.—The Greenwich time for the middle of the partial lunar eclipse, July 24, 1907, was $16^h\ 22^m$, what was the corresponding local time at Santa Fé, N. M.?

The longitude of the place is $7^h\ 4^m$ W. (Appendix), and this time subtracted from the Greenwich time above gives $9^h\ 18^m$ P. M., as the required local time at Santa Fé (Jayne's Almanac, 1907, p. 1).

67. Field of view and magnifying power of opera-glasses.—The circle of light seen when opera-glasses are pointed at the sky (§ 52) shows how much space is visible at one time, and that is the field of view of the glasses. There is no object in determining it rigorously, but its value is easily found approximately either from moon or stars. Thus, with the full moon in the field of view, estimate how many moons, placed close together, would be required to reach centrally across the field, and half that number is the diameter of the field in degrees (Young, Art. 152). If stars are employed, pick out two near the equator, and just far enough apart so that both can barely be brought into the field together, *i. e.*, appearing practically at the extremities of one of its diameters. The distance between them, measured on map or globe, gives approximately the diameter sought.

To find the magnifying power of opera-glasses, it is necessary to ascertain how they affect the diameter of an object. If, for example, the magnified image has a diameter three times as great as that of the object itself, the power of the glasses is said to be three. In making this test, it is at first often difficult to get at the same time a clear, steady view of the object and its magnified image; and to place and hold the latter while estimates are being made. It is not amiss, therefore, to give a preliminary exercise to practice, and defer till later the record of estimates. Details are best illustrated by an example.

EXERCISE.—Fraser Hall, State University, Lawrence, Kan., 11^h A. M., Saturday, March 13, 1909, I take first a piece of plotting paper on which some of the lines have been reinforced with black ink, so as to mark out very distinctly three rectangles. This paper, fastened to stiff cardboard, is fixed in a vertical position some distance from where I sit. Turning the opera-glasses toward it and using both eyes, I focus carefully on an irregular cross drawn on the paper. Then, looking directly at the rectangles with the right eye, and with the other through the glasses, I bring the magnified image of the one on the left to coincide exactly with the left-hand side of the figure itself. In this position, the magnified image appears to extend over 2.4 diameters of the unmagnified rectangles.

To obtain another test, I focus the glasses on a window with three panes in the width of the sash, and find that the image of the pane on the left covers 2.5 panes as seen directly. (J. F. B.)

Whatever object is employed, the eye should be as far from it as possible, so that the focus will differ but little from that used with heavenly bodies. The mean of five or six measures made on two dates gives a satisfactory value for the magnifying power, a power that should always be expressed, as here, in diameters, not in areas.

68. Focal length and field of view of small telescope.—To find the focal length of a small telescope, remove the eye-piece,

direct the tube toward the sun, and let its image fall on a piece of white cardboard held near the eye end. Keeping the card at right angles to the axis of the tube, shift it back and forth till the sharpest image of the sun is obtained, and then measure the distance between the card and the end of the tube. This distance added to the length of the main tube gives the focal length, approximately (Byrd, § 20, *b*).

The field of view differs with different eye-pieces. Its diameter, expressed in time, is the interval required for a star on the equator to pass centrally across the field. In making the actual determination, however, a star that has high, north declination is to be preferred, though it is desirable to observe more than one.

OBSERVATION.—Williston Observatory, Mt. Holyoke College, South Hadley, Mass., Tuesday, June 2, 1908. In order to find the field of view of a portable telescope, aperture 2.5 inches, and eye-piece magnifying 24 diameters, I observe α Virginis. The telescope is directed to the star a little before it reaches the meridian, and the following times recorded from a common watch:

α Virginis	enters field,	$8^h\ 18^m\ 31^s$
α "	leaves "	8 24 18

The watch interval for the passage of this star is then $5^m\ 47^s$ or $5^m\ 48^s$, in sidereal time, and the reduction to the equator, is made as follows, by multiplying by the cosine of the star's declination:

$\log 5^m\ 48^s = \log 348^s$,	2.5416
$\log \cos$ Decl. $= \log \cos (-10°.7)$,	9.9924
log of equatorial interval,	2.5340
equatorial interval,	$5^m\ 42^s$

This value combined with another obtained from the same star, and with one from α Cephei, gives a mean result of $5^m\ 39^s$ or $1°\ 25'$. That is, with this telescope and eye-piece, the section of the heavens visible at one time is a circle with a diameter of $1°.4$, measured on the equator. (A. L. O.)

CHAPTER VI.

FIRST OBSERVATIONS WITH TELESCOPE; LUNAR ECLIPSES; COMETS; APPEARANCE AND MOTION OF STARS; POSITION OF EQUATOR, ECLIPTIC, AND MILKY WAY; LATITUDE FROM STARS; TIME FROM SUN-DIAL; CHARTING DIURNAL PATHS; MAGNIFYING POWER OF TELESCOPE; PROFICIENCY OF OBJECT-GLASS.

69. Sun and moon with small telescope.—The allotment of time in due proportion among different kinds of observations will not leave many hours for the telescope, and several must be devoted to preliminary tests and adjustments (§ § 53, 54, 68, 81). An ambitious program should not be undertaken with any heavenly body. For the sun, three or four periods, about fifteen minutes in length, ought to suffice for reviewing points suggested with opera-glasses (§ 55), and for examining sun spots on different days, to find in what direction they are moving, and what changes take place in a short interval. Even with a small telescope the solar disk may be studied from projections on white cardboard, but direct views are more satisfactory; and if the objective is less than three inches, the eyes can be protected by placing several pieces of colored glass in a cap covering the eye-piece. It is hardly safe, however, to trust to one piece of glass, no matter how thick and dark.

Rather more time should be given to the moon than to the sun; for, with a small telescope, more can be seen on the moon than on any other heavenly body. Two observing periods, an hour in length, serve very well, provided they come in different lunations. In the first, progress will doubtless be slow, if, as often happens, use is first made of the telescope in studying the moon; but at the end of the second, there should be, in all, as many as twenty objects identified. More than twice that number can be sketched in an hour by an experienced observer when the phase of the moon is favorable (Byrd, § 216).

Whenever a telescope is used in observing, it is essential to state in the notes the aperture of the objective and the magnifying power employed.

70. **Lunar eclipses.**—Eclipses of the moon afford excellent training for beginners in seeing and recording. Unlike many observations, they present a continuous series of phenomena, extending over a considerable length of time, and marked by a beginning, culmination, and decline. In preparing to observe them, a list of exercises should be made out and studied beforehand (§ 82, Byrd, §§ 133, 149), so that during the eclipse no time need be lost in planning what to do and when and how to do it. Most of the observations should be made with the unaided eye, but if there has been some practice with opera-glasses and small telescope, they are properly used in connection with a few points.

Lunar eclipses are not an every-day occurrence, and when one does come during the astronomical course, it merits a generous amount of time and attention.

71. **Shooting stars.**—Notwithstanding the rapid motion of shooting stars, practice enables the observer to decide definitely about a number of their characteristics; as, for example, how they are moving with regard to the horizon, how they compare in color and brightness with stars or planets, whether they are followed by trains of light, whether there are differences in their rates of motion, and where they appear and disappear, that is, in what part of a particular constellation they are seen at first and at the last.

On almost every evening, when it is clear, some shooting stars are seen, and on certain dates their number is large, and their fall is known as a meteoric shower. That of the Leonids is one of the most noted (Byrd, § 178).

72. **Appearance and motion of bright comets.**—Once in about three or four years, on the average, a comet appears that is vis-

ible to the naked eye, and at longer and more irregular intervals, a really bright one is seen, like that discovered by Zaccheus Daniel in June, 1907.

Beginners, as well as astronomers, should be interested both in the motion of comets on the celestial sphere, and in their physical appearance. Thus, a complete record should include estimates of distance and angle for locating the head or nucleus among the stars; and careful notes regarding color and brightness, and the size and form of the constituent parts. Since the interest and value of observations increase with their number, a comet should be followed as long as it is visible with opera-glasses, and some data obtained, if possible, on every clear night.

In partial illustration of these suggestions, the following examples are given:

Observations 1.—W. V., Lawrence, Kan., Monday, Aug. 26, 1907. The moon, which is now midway between full and last quarter, lights up the eastern sky, there are also some clouds, and twilight is approaching; but in spite of these drawbacks, Daniel's comet is fairly bright at 4^h, A. M., C. S. T., and remains visible to the naked eye till nearly 5 o'clock. Opera-glasses show little detail, but a small telescope, with an eye-piece magnifying 60 diameters (§ 81), gives a good view of the head. It is large and bright, the light seeming to be in streams, as if from a flowing fountain. The nucleus has a tinge of yellow, is oval in shape and eccentrically placed. The whole effect resembles that depicted for the great comet of 1882, except that the outer envelope spreads farther away from the axis, leaving larger dark rifts on either side. ("Young's General Astronomy," Art. 751.)

A few days later, the head was found to be much smaller and the fountain-like effect had disappeared.

Observation 2.—519 Oakland Avenue, Pasadena, Calif., Saturday, Sept. 7, 1907. Looking out about 4^h, A. M., P. S. T., I find Daniel's comet appearing just above the horizon. The seeing is excellent, and I can follow the tail with the unaided eye nearly 20°. It extends upward and a little to the south, that is, it points away from the sun.

In order to fix the comet's position, I employ three comparison stars, α and β Cancri and ζ Hydræ, as shown in Fig. 10. The comet's distance from α, I estimate as three fourths that between α and β and also one and a half times that between α and ζ. The line connecting β, α, and the comet is not quite a straight line but bends downward a little at β, and the angle at α between ζ and the comet is a little more than a right angle. My final numerical estimates are, therefore:

Position 1.—$\angle \beta \alpha$ Cancri ☄ $= 175°$, α Cancri ☄ $= \frac{3}{4}$ $\alpha \beta$ Cancri.
Position 2.—$\angle \zeta$ Hydræ α Cancri ☄ $= 95°$, α Cancri ☄ $= 1\frac{1}{2}$ α Cancri ζ Hydræ.

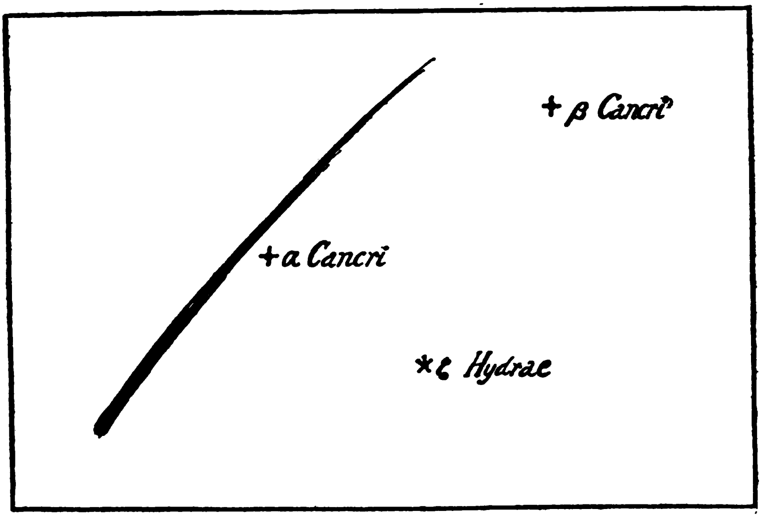

FIG. 10.—Daniels' Comet in Cancer.

In like manner, I obtained nine positions of the comet, the first two in August, in the San Jacinto Mountains, about a hundred miles southeast of Pasadena, and the others at the latter place. To the last, the comet was visible to the naked eye; but, owing to twilight, opera-glasses were almost always used in identifying the comparison stars. (L. B.)

These observations plotted on the celestial globe (§ 51, Ex. 4) bring out several features regarding the comet's motion. Its path, during the period of observation, is found to lie entirely north of the equator, extending in a direction south of east, over 55°, through the zodiacal constellations, Gemini, Cancer, and Leo. There is slight change in velocity, though at the beginning motion is rather faster than at the end.

The coördinates derived from the first, fifth and last observations, including precession (§ 59) are:

1907,	Aug. 15^d $15^h.7$:	R. A.,	6^h 43^m;	Decl., $+18°.0$
"	Sept. 6 16 .3:	R. A.,	9 29;	Decl., $+13$ .1
"	Sept. 17 16 .5:	R. A.,	10 24;	Decl., $+$ 7 .5

The whole change, therefore, in 33 days amounted to a little over 3.5 hours in right ascension, and in declination to about 10°, showing that the comet was moving slowly, compared with the moon (§ 58), but more rapidly than Venus (§ 83, Obs.).

Observations like these are, of course, not in the same class as those taken by astronomers with equatorial telescope and filar micrometer. In order, however, to obtain some standard of comparison, eight positions fixed at observatories in August and September are plotted on the globe, and the corresponding path for the comet marked out with heavy thread (§ 57). The path laid down from eye-estimates is then seen to coincide in places with this "observatory path," and at most deviates from it only about half a degree. This check is suited only to elementary work, but it shows that results are as accurate as would be expected from observations taken by the eye, aided only with opera-glasses.

73. Color and brightness of celestial objects.—To distinguish even marked differences in the color and brightness of celestial objects requires training. At first, special care should be taken to observe only under favorable conditions, when the sky is clear, unaffected by twilight or moonlight, and the objects con-

sidered are well above the horizon. Exercises like the following may serve as a guide:

1. When three or more of the bright planets are visible, pick out, if possible, one that is clear white in color, one tinged with red, and one, with yellow.

2. Make a list of eight or ten of the brightest stars seen in one evening, and examine them individually, noting which are clear white, which tinged with red, and which, if any, with yellow.

3. Should a bright comet be visible, note the color of its nucleus.

4. Repeat exercises 1 and 2 in different seasons, if practicable, so as to bring under scrutiny all the bright planets, and all stars of the first magnitude, visible at the given place.

5. When as many as three bright planets are visible, estimate which is the brightest, which ranks second, and which third. Note also their relative variation, whether, for instance, the difference between Jupiter and Venus is greater or less than that between Jupiter and Saturn.

6. In the year when Mars is an evening star, make an approximate determination of its varying brightness, using each time, if possible, a red star for comparison (Byrd, § 168).

7. Make a list of eight or ten of the brightest stars seen in one evening, and then arrange them in order of brightness.

8. When Algol, *i. e.*, β Persei, is of maximum brightness, compare it with α Persei, and taking a "step" as the least difference recognized in brightness, estimate whether the variation between them is one step or more (Byrd, § 205).

9. On a date when a minimum is predicted for Algol in the evening, compare it with neighboring stars, three or four times at intervals of about an hour. Select, if possible, each time a star that Algol just matches in brightness, or if that is impracticable, indicate by steps the relation between the two (Byrd, § 206).

In dealing with the varying brightness of any object, care should be taken in choosing comparison stars. They should not be near brighter stars nor differ much in color from the vari-

able. It is also important for the comparison star to have about the same altitude as the variable, and be near it in the heavens, though no effort is to be made to look at both at the same time.

74. Apparent motion of the stars.—A single night's study of the heavens suffices to show that the stars do not remain fixed in regard to the horizon or other circles of reference. To find out the law that governs their motion, a number of different observations should be taken. It is well to include simple ones, such as watching to see whether stars low in the east and west are rising higher or sinking lower, and whether those well up to the south and north are moving toward the eastern or western quarter of the horizon. Note also the times when bright stars rise or set and their places on the horizon. If the principal constellations have been grouped in reference to the four quarters of the heavens in different seasons (§ 20, Obs.), compare the two observations, and see what changes have taken place.

The following are often included among the more formal observations made:

Exercise 1.—On an evening in the fall and again in the spring, make two sketches of the "great dipper" in reference to the horizon, with an interval of two hours, if possible, between them (Byrd, § 193).

Exercise 2.—Twice in the same evening, allowing an interval of two hours, make note of the position of several of the circumpolar constellations in reference to the North Star and to the cardinal points.

Exercise 3.—Twice in the same evening, allowing an interval of two hours, note the position of three bright constellations, one chosen near the eastern horizon, one near the meridian, and the third near the horizon toward the west.

Final conclusions should be formulated as fully and critically as warranted by all the data obtained.

75. Position of ecliptic and celestial equator.—These reference circles are marked on globes and star-maps, and if the individual

stars on or near them are noted and carefully identified in the sky, the circles can be traced out there. Of course, only half the celestial sphere is visible at one time, but if two observations are taken about six months apart, both the ecliptic and equator can be followed throughout their course, and something learned regarding their position in reference to the horizon of the particular place.

OBSERVATION.—S. C. O., Northampton, Mass., 8^h P. M., E. S. T., Wednesday, April 1, 1908. From the observing roof over the laboratory room, I locate the ecliptic in the sky, having on a previous night identified the stars along its path. Beginning near the eastern horizon I trace it,

1. Between α and θ Virginis,
2. Below and parallel to $\eta\beta$ Virginis,
3. Through ρ and α Leonis, δ Cancri and δ Geminorum,
4. To the right of ζ Tauri by about $\frac{1}{4}$ $\zeta\beta$ Tauri, and a trifle below τ and κ Tauri.

The ecliptic, I find, intersects the horizon, south of the east point, over the right-hand end of College Hall; and north of the west point, behind the left-hand poplar tree in the foreground. Its highest point is reached at δ Cancri, and the altitude of this star, from three measures made with jointed-rods and protractor is 68°, the check on the globe giving 65°.

I noted also that the three bright planets visible were close to the ecliptic, Jupiter near its highest point and Mars and Venus rather low in the west.

In like manner, at the same place, on the same date, about a quarter of an hour later, I trace the course of the equator, following it,

1. Through ζ and η Virginis, barely
2. Below α Sextantis, a little
3. Above ι and τ Hydræ and
4. Through δ Monocerotis and δ Orionis.

It meets the horizon in the east, over the left-hand end of College Hall; and in the west, over the buildings on Hospital Hill, in the distance, or just to the left of the large elm tree in the fore-

ground. At its highest point, it coincides almost exactly with the star, τ Hydræ, close to the meridian at this time; and having, according to my measures, an altitude of 48°. The theoretical check gives 47°.7, if τ is assumed to be just on the meridian.

(E. H.)

76. Form, position and motion of the Milky Way.—The time to observe the Milky Way is when the sky is really clear and there is no moon. The place should be as free as possible from the effect of artificial light, and in order to see faint outlying parts of the stream, the eyes should be kept in the dark a little before observing begins. If, as is to be assumed, the constellations are well known, no lights should be employed till at the end, when numerical estimates are made, or measures taken and other notes recorded. To follow the Milky Way throughout its whole circuit, and to find whether it changes its position in reference to the observer's horizon will require two or more observations, in different seasons of the year, somewhat like the following:

Observation.—Sunday, July 26, 1908, Goshen, Mass. Preparatory to observing the Milky Way, I have already located an approximate north and south line on a large stepping stone (Byrd, § 9,*c*); and, by aligning from it, fixed the west point on the horizon. A suitable resting place for jointed-rods has been obtained by nailing a board to the top of the hitching post and leveling it up.

Looking at the sky this evening between half after nine and ten, I find the arch of the Milky Way spanning the heavens in the east, meeting the horizon near the north and south points, and where it is highest passing close to β Cygni. Its course is traced from the lower part of Scorpio at the south, up through the upper part of Sagittarius, through Scutum, Aquila and Cygnus, and down through Lacerta and Cassiopeia at the north. In Cygnus, the main stream divides into two branches, the smaller one extending into Ophiuchus with Serpens winding its way between them. The brightest as well as the widest part of the main arch seems to be in Sagittarius with a diameter equal to the star-line, $\sigma\gamma$ Sagittarii or about 11°. By a rough eye-estimate, I make the

altitude of the highest point $\frac{7}{8}$ of the distance between horizon and zenith, that is, 79°. The mean of three measures with jointed-rods and protractors gives 71°. As a whole, I find the Milky Way an irregular stream of light, with a diameter by turns widening and narrowing. The branch, especially, is irregular in contour, and in places appears more like patches of light than a continuous stream. (A. M. H.)

Though it may not be practicable to obtain ideal conditions for the Milky Way, it should not be altogether neglected. Something of it can be seen even in the vicinity of electric lights; and if its intersections with the horizon are fixed approximately on a single night, a clue is given as to whether the arch is a small or a great circle.

77. Stars and nebulae with opera-glasses.—If two short periods on different dates are given to this topic, the working-list (Byrd, § 1) should include the star-clusters of the Pleiades and Coma Berenicis, the nebulæ of Andromeda and Orion, and a few wide doubles, such as ζ Ursæ Majoris and α Capricorni (§ 84, 7). Whatever object is examined, the aim should be to find answers to definite questions. For example, with α Capricorni, see whether the components are equal or unequal in brightness, alike or unlike in color, how they resemble in these respects the components of ζ Ursæ Majoris, and how the distances separating the stars of the two doubles compare (Byrd, § 204).

It should be borne in mind that the main object in observing heavenly bodies is not to see something pretty, but to find out something.

78. Latitude from altitude of stars.—The North Star, also called Polaris, is the star to employ in finding latitude. Were it exactly at the pole, that is, if its declination were just 90°, its altitude observed at any time would give latitude directly; for the altitude of the pole equals the latitude of the place. The declination of Polaris is, however, 88°.8, so that when it crosses the meridian above the pole, its altitude is 1°.2 greater than the

latitude, but when it crosses below the pole, its altitude is smaller by 1°.2.

Even if Polaris is not on the meridian, its altitude may still be utilized in finding latitude; for the difference between the altitude of pole and star depends upon the star's hour-angle at the time of observation, and when that is known, the required correction can be taken from Table IV in the Ephemeris. This table, now called Table I, has appeared since 1911 in an extended form, and is entered with two arguments, as explained in the introductory paragraph.

Observation.—Kansas University, Lawrence, Tuesday, Dec. 22, 1908. The Circles (§ 12) are placed approximately in the meridian on the north porch of the physics' building to measure the altitude of Polaris. The base is leveled with a carpenter's level, and a little before six in the evening, four readings are taken for altitude, two with the vertical circle facing east and two with it facing west. The mean value for the angle is 39° 47′, and the mean of the corresponding times, $5^h\ 52^m$, c. s. t., or $23^h\ 35^m$ sidereal time (§ 64, Ex.). When observed, the star was, therefore, $1^h\ 51^m$ east of the meridian (Byrd, § 39, current Ephemeris, p. 595), and the correction opposite this hour-angle in Table IV is found to be, −1° 3′, which, if refraction is included, makes the required latitude 38° 43′. (El. H.)

The following is a concise form of arrangement for the numerical operations:

Table V.—Latitude from Polaris.

Stand. T. of Obs.	5^h 52^m		
Stand. M.E. of Lawrence	21	Obs. altitude	+39° 47′
Mean local T. of Obs.	5 31	Correc. for Refrac.	− 1
Sidereal T. of Obs.	23 35	Correc. fr. Table IV	− 1 3
R. A. of Polaris	1 26	Latitude fr. Obs.	+38 43
Hour-angle of Polaris	22 9		
	(−1 51)		

A mean value for latitude, obtained by combining this determination with two others, made within the hour by the same observer in the same way is 38° 52′, which is 5′ less than the true value for the University (§ 87, Ex. 1).

If the meridian altitude of a star south of the zenith is employed for latitude, choose one that is bright and below rather than above the equator. Neither Antares nor Fomalhaut is too far south to be satisfactorily observed (Byrd, § 1, last part). Instead of a star, a bright planet may be used, if its southing is low enough, and comes at a convenient time. The reduction, either for star or planet, is made just as for the sun in Ex. 2, § 44.

79. Adjusting and reading a sun-dial.—It is not practicable to give directions that always apply in adjusting a sun-dial. Much depends upon its precise form, and the place where it is to be used. Sometimes also, account must be taken of the season of the year; for the time during which a dial, fixed on a window sill, is in the sunshine varies largely from month to month.

If the essential condition is met, that is, if the dial can be read at sun noon, it is usually satisfactory, with the sun-dial illustrated in Fig. 11 (the same as Fig. 3) to proceed somewhat as follows:

First place an upright with heavy base and movable arm, so that a plumb line suspended from the latter passes through the center of the upper part of the style. Just under the point of the bob, mark a dot, and later, on different days with different plumb-bobs, adjust and check its exact position. Then connect the mark thus fixed with the center of the style where it joins the base of the dial, and the line drawn gives the intersection of a plane that is nearly vertical, and passes almost exactly through the central line of the style.

The next step is to bring this line into the plane of the meridian. After a rough adjustment has been made, shift the base slightly east or west, at the instant of sun noon. Several trials on different days may be required, but in the end the line should lie in the center of the beam of sunlight at sun noon. Finally, the sheet of paper, graduated to hours and parts of an hour, for the

latitude of the place, is fastened on the base, with its noon line coinciding with this meridian line.

The style should be placed accurately at the proper angle when the sun-dial is first made, but sometimes a slight correction is necessary. In that case, loosen the screws on the

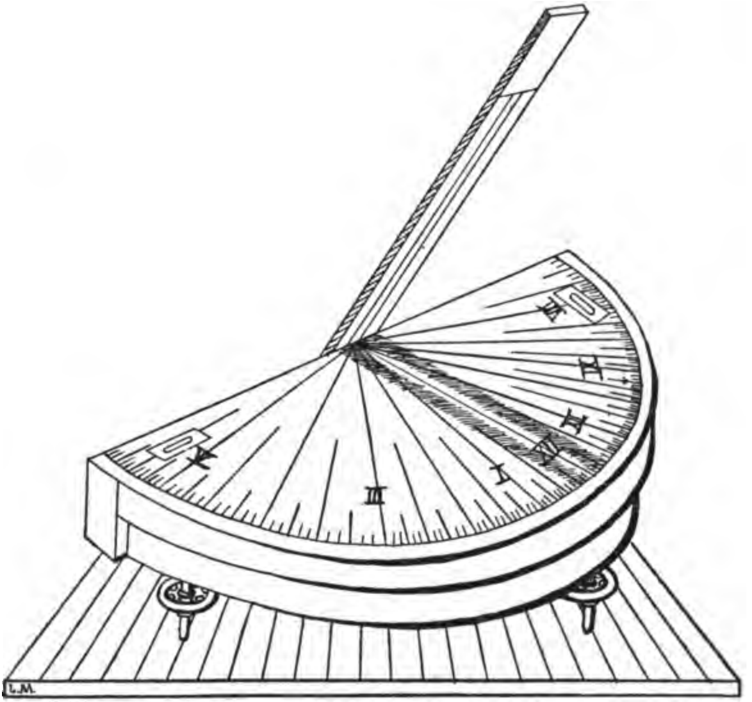

FIG 11.—Open-Style Sun-Dial.

supporting block, and crowd a small wedge between the block and the style, either at the bottom or top, according as the angle of altitude is too great or too small. In making this adjustment, bear in mind that raising the style makes the sun-dial time slower before, but faster after, sun noon, and that just at this instant an error in the altitude of the style has no effect upon the time.

OBSERVATION.—N. C., New York, N. Y., Tuesday, Sept. 2, 1913. The sun-dial employed is like that of Fig. 11, page 93, approximately adjusted according to the preceding directions. It would be a waste of time to make a very critical adjustment, for the instrument is a rough, first model, with imperfect graduations, and doubtless an error in the altitude of the style.

The readings taken from watch and dial are:

Sun-dial.	Watch.
$12^h\ 35^m\ 0^s$	$12^h\ 31^m\ 42^s$

In order to compare these two times, they must be alike, *i. e.*, both apparent or both standard. The sun-dial time is, as usual, reduced to standard, thus,

Sun time,	12^h	35^m	0^s
Equation of time,			-19
Local mean time,	12	34	41
Stand. Merid. W. of N. Y.,		4	9
Stand. time fr. Obs.,	12	30	32
Stand. time fr. watch,	12	31	42
Error of watch by Obs.,		-1	10

Since the true error of the watch, according to the standard clock of the Western Union Time Service was 57^s fast, to the nearest second, the error of the sun-dial was, $+13^s$. Two other readings taken between twelve and one o'clock made the error of dial time, $+9^s$ and, $+12^s$.

80. Diurnal paths charted.—A number of diurnal paths can be brought into small compass, in convenient form for comparison by plotting them on rectangular paper. As an illustration a series of actual observations is taken. All were made with the same instrument, the Circles (§ 12), and in the same manner (§ 30). Other details, including place and date are given in the following table:

TABLE VI.—DIURNAL PATHS, S. C. O., NORTHAMPTON, MASS., 1908–1909.

DATE OF OBS.	DESIGNATION OF PATH.	DECLINATION OF BODY.	OBS. MER. ALTITUDE.	INITIALS OF OBSERVER.
1908				
March 24	Sun, $S_1 S_1$	+ 1°.5	49°.0	F. J. D.
March 24	Venus, VV	+18.4		M. E. J.
April 24	Sun, $S_2 S_2$	+12.9	61 .2	H. B.
June 17	Sun, $S_3 S_3$	+23.4	71 .0	E. H.
Sept. 21	Sun, $S_4 S_4$	+ 0.7	48 .9	E. C. M.
Nov. 16	Sun, $S_5 S_5$	−18.8	28 .6	E. C. M.
Dec. 21	Sun, $S_6 S_6$	−23.5	24 .0	K. K.
1909				
May 26	Moon, MM	+14.9 (on Merid.)	63. 2	A. H.

All points obtained for the eight paths are plotted in Fig. 12, from measures of altitude and azimuth, contained in the original notes. The reference lines employed are a section of the horizon, the heavy line near the bottom, with *E* and *W*. marking the east and west points; and that part of the celestial meridian between the zenith and the south point. Note, that *SZ*, *SE*, and *SW* are equal each to each, as each is the projection of the quadrant of a great circle. To show how any individual point is located, let it be required to fix the position of Venus when its altitude is 41°.1 and azimuth 78°.4, a degree according to the scale taken, being equal to $\frac{7}{9}$ of a division of the rectangular paper used. The number of divisions corresponding to the given altitude and azimuth are then $\frac{7}{9}$ of the number of degrees in these coördinates, or 32.0d and 61.0d, respectively. Now, as azimuth is reckoned along the horizon from the south point toward the west, 61.0d are counted off from *S* toward *W* on the horizon line, and then 32.0d laid off vertically above this point locates the planet near the upper V in the diagram.

Fig. 12 and the table above give a general idea of the amount and character of the observing that should be undertaken for diurnal paths, though no special significance attaches to the dates for Venus and the moon, and any bright planet may be taken though Venus and Mars are especially interesting (§ 83).

In the dates for the six solar paths, there will inevitably be large variations, and the individual observer is fortunate if one of them comes near an equinox and another near one of the solstices (§ 31). The large number obtained at or near such times, in the series considered, is due mainly to the fact that different paths were traced by different observers.

It is well, as here, to obtain for every path, when practicable,

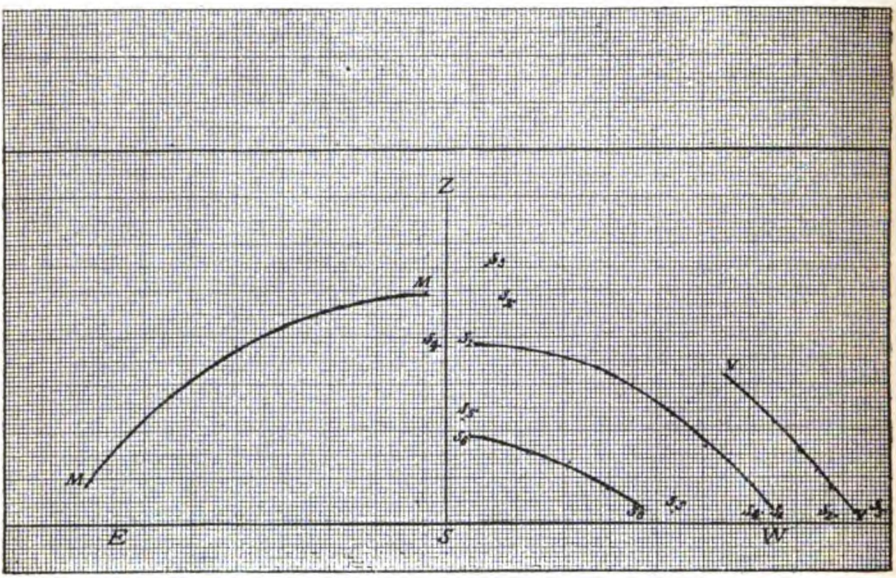

FIG. 12.—Diurnal Paths of Sun, Moon, and Venus.

the critical point near the meridian, since examination of diagram and globe shows that, if one point only is fixed, this gives the most satisfactory key to the path for the day. It is also the one most readily checked, for declination subtracted from observed altitude gives in each instance the approximate meridian altitude of the celestial equator at the place of observation (§ 28). Thus, from columns three and four of the table, the value derived for the meridian altitude of the equator is 47°.8, as against the true

value 47°.7, and from the mean, the largest deviation is five-tenths of a degree. The value for latitude found from this altitude of the equator is, of course, as accurate as the altitude.

When five or more points have been fixed for the path of any one body, its course is marked, as in the figure, by a smooth curve, and the deviation of an individual point from the curve gives a test of the accuracy of its altitude and azimuth. Even for isolated points, an approximate check is obtained by a careful scrutiny of all the data, and when a path is indicated by two or three points, the eye following the general direction of adjacent curves gains a fair notion of the path as a whole.

A simple diagram of diurnal paths stands for many and laborious observations, and when it is completed it deserves thorough study. The following points especially should receive attention:

1. Relation between changes in noon altitude and sunset point.
2. Connection between position and extent of solar paths and seasons of the year.
3. Connection between position and extent of any path, and declination of the body.
4. Likeness or unlikeness of paths for different bodies.

Considerations of this character should also be supplemented by exercises with the celestial globe, especially such as show how portions of diurnal paths on one side of the meridian compare with those on the other, and whether any given path is part of a small or a great circle.

81. Magnifying power of small telescope and quality of object-glass.—A simple method for determining the magnifying power of a telescope consists in dividing the diameter of the object-glass by that of the small circle of light, which is seen close to the eye-piece, when the glass is turned toward the sky in the daytime. This circle is, in reality, the image of the objective aperture diminished in the same proportion as the telescope magnifies. Its diameter may be determined by Berthon's Dynamometer, or by almost any form of scale when a high degree of precision is not required. (See "Campbell's Practical Astronomy," § 150).

EXERCISE 1.—Fraser Hall, K. U., Tuesday, July 13, 1909. Having adjusted the portable transit-instrument, approximately for stellar focus, I take three measures of the diameter of the objective by laying a common foot-rule on the cell and aligning downward by the eye. With a home-made scale (Byrd, § 20, *c*), I measure also the "circle of light" three times.

Like tests are applied on two other days of the same week, and the mean of ten measures for each diameter is found to be 1.90 in., for the objective, and 0.14 in. for the circle, which gives 13.6 diameters as the magnifying power of the instrument with the diagonal eye-piece. (El. H.)

The efficiency of a telescope depends largely upon the quality of the object-glass. It ought to show stars like points of light, and all images sharp and clear-cut without "wings of light" or extraneous color.

Irradiation, or the so-called wing of light, on one side of a bright object, usually indicates that all parts of the objective have not the same refractive power; blurred images indicate spherical aberration, that is, light from a single point in the object has not all been brought to the same point in the image; and images of variegated color indicate chromatic aberration, that is, light rays of different color have not all been brought to the same focus.

With a home-made telescope, a wing of light sometimes appears which is caused by inaccurate centering of the different lenses.

EXERCISE 2.—K. U., Saturday, July 10, 1909. In testing the objective of the portable transit instrument, Jupiter is first brought into the field of view, and the eye-piece carefully focused. No wings of light are seen, the outline of the planet is sharply defined, and two satellites are visible. To test for chromatic aberration, I draw out the eye-piece a little, and find a fringe of light green at the upper part of the disk. When the eye-piece is pushed in, there is seen, on the upper limb to the right, a pale fringe of different colors, but it is far less distinct than that first mentioned.

Two stars are examined in testing for spherical aberration. First, I obtain a sharp image of the second magnitude star, β Leonis, and note that a slight inward motion of the eye-piece has no effect, but when it is drawn out the star is not quite so sharp. Then, with ϵ Virginis, a third magnitude star, in good focus, I try the effect of a cap placed over the objective and covering half its diameter. I find that the star image remains as sharp as at first, but is, of course, diminished in brightness. (El. H.)

The objects observed were rather low when these tests were made, which, perhaps, accounts for the fact that results do not agree more closely with those required by theory for a fully satisfactory instrument.

Many helpful details connected with the adjustment and use of a small telescope are given by Proctor in his "Half-Hours with the Telescope."

CHAPTER VII.

PARTIAL SOLAR ECLIPSE; PATHS OF PLANETS; PLANETS AND STARS WITH SMALL TELESCOPE; GENERAL PROBLEM OF TIME WITH TRANSIT INSTRUMENT; TIME FROM TRANSIT INSTRUMENT; LONGITUDE FROM TIME.

82. Partial solar eclipse.—Astronomers attach little importance to any eclipse except a total one of the sun. Nevertheless, in an elementary course in astronomy, all eclipses, whether of the sun or the moon, deserve careful study. This is especially true of a solar eclipse, for even the partial phase is not often visible in any one locality.

The mechanical appliances for observing should include card-patterns for drawing circles, some instrument for measuring the sun's altitude, a number of spectacles with glass of varying shades suited to different phases of the eclipse, and opera-glasses or small telescope. The eye-piece of the latter must be carefully protected (§ 69), and all watches employed compared with a correct time-piece. The main points to be considered may be arranged in a scheme something like the following:

Points Connected with Beginning of Eclipse.

1. A little before first contact, make note of the sun's altitude, and record whether or not the sky is free from haze and clouds, especially near the sun.

2. Draw a circle for the solar disk, indicating which is the east and which the west limb.

3. Record the time of first contact, that is, the instant when the limb of the sun is first indented.

4. Locate the point where the eclipse begins by a mark on the circle representing the solar disk.

5. During the ten or fifteen minutes following first contact, show the progress of the eclipse by drawing on the solar circle

several arcs which mark the boundary between the eclipsed and uneclipsed portions. Include also a record of the times corresponding to the arcs.

Points Connected with Maximum Phase.

6. As the time predicted for this phase approaches, indicate the progress of the eclipse as in 5, passing to a second solar circle, as soon as the eclipsed portion begins clearly to diminish.

7. Estimate what proportion of the solar circumference is indented, and how far in the indentation extends, expressed in terms of the sun's diameter.

8. Describe the general appearance of the sun, noting whether the moon's limb can be followed beyond the solar disk.

9. Note whether the sun's light at this time shows any peculiarity.

10. Examine and describe the images of the sun seen under trees or shrubs (§ 42).

11. Look at the sun with opera-glasses or small telescope, and, if any spot is visible, locate it on one of the solar circles.

12. Describe points of difference between the view given by the telescope and that observed directly.

13. See if any bright star or planet is visible with opera-glasses.

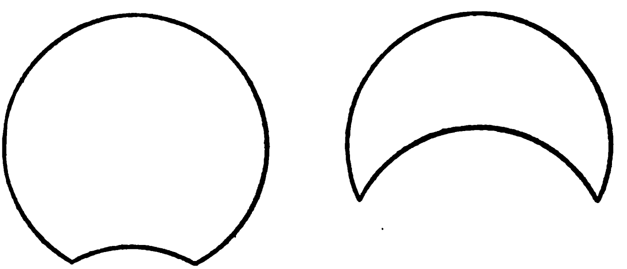

Fig. 13.

Points connected with the end of the eclipse are so similar to those considered at its beginning that one outline, with slight modifications, serves for both. The diagrams in Fig. 13 show

the solar disk when one-tenth and six-tenths of its diameter are eclipsed, and give an idea of the illustrations desired, though for the note-book, the scale ought to be larger. Any scheme that is to be used as a guide should, of course, be studied before the eclipse begins.

83. **Paths of planets among the stars.**—Two of the bright planets, Jupiter and Saturn, move so slowly that during a period of several months only short sections of their paths can be obtained. Venus and Mars on the other hand move so rapidly, and are so bright that in seasons when they are favorably placed for observing, it is not difficult to trace their course in the constellations through 60 or 70 degrees (Byrd, § 171). Mercury, on account of its nearness to the sun, is not often seen at the same time with the stars. To identify it and fix two or three points in its path on the sphere, measures may be made of its altitude and azimuth when it is visible in bright twilight (§ 51, Ex. 1). This is a method applicable also to the other planets; but for them it is best to make a series of sketches on different nights, fixing positions in reference to comparison stars by careful estimates of distance and angle (§ 59).

In checking and combining such sketches and in making deductions from them, no mechanical appliance equals the celestial globe, but to facilitate the work of a whole class, and to assure for each member a permanent record, it is well to prepare a special map on heavy cardboard, much larger in scale than the small uranographies. Let it contain, as far as practicable, the usual reference circles, including sections of the equator and ecliptic, and all stars used by the class with others needed to give a good representation of that portion of the heavens observed. All who have taken part in the observations enter, then, in their note-books a tracing-paper copy of this map, and fix on it with precision the different points determined by the individual data obtained. A smooth curve drawn through the points shows at a glance the path of the planet watched in the sky from night to night.

The following observations of Venus illustrate a number of details, though it will not often be practicable for an individual student to obtain so many positions. Eight or ten is a fair number.

OBSERVATION.—Whitin Observatory, Wellesley College, Wellesley, Mass. During the spring of 1908, I located 30 points in the path of Venus among the stars. Neither mechanical nor optical aids were employed, except that a marine glass was used on three nights in identifying comparison stars. In several instances, observations followed on successive nights, but two or three days was the usual interval, All but three were taken here and those were obtained in Boston. (M. W. D.)

The 30 points mentioned above are fixed by dots in Fig. 14, on the following page. The numbers near them indicate the order in time, and the curve drawn through them shows the path traced for Venus. It is seen to lie north of the ecliptic but always near it, and to extend eastward through the zodiacal constellations, Aries, Taurus, and Gemini, passing near the Pleiades. In order to ascertain its extent in degrees and for other deductions, recourse must be had to the celestial globe. From the plot made there, the entire length of the path during the 85 days between the first and last observations measures 70°. As required by theory, the rate of motion in this path varies largely; for the planet passed over 11°.5 during the first ten days, but only over 3°.5 during the last ten, which includes the position marked stationary in the almanacs. The coördinates of the first and last positions and the declination of "farthest north" were obtained from the globe, and the results with the corresponding values from the Ephemeris are:

Date.	R. A. fr. Obs.,	fr. Ephem.;	Decl. fr. Obs.,	fr. Ephem.
March 21, $7^h.8$	$2^h\ 38^m$	$2^h\ 42^m$,	+16°.3	+17°.3
		(*Farthest north*)	+26 .5	+27 .0
June 13, 9 .0	7 35	7 35 ,	+22 .5	+22 .5

It follows, therefore, that during the period of observation, Venus moved east about 5 hours in right ascension, but in

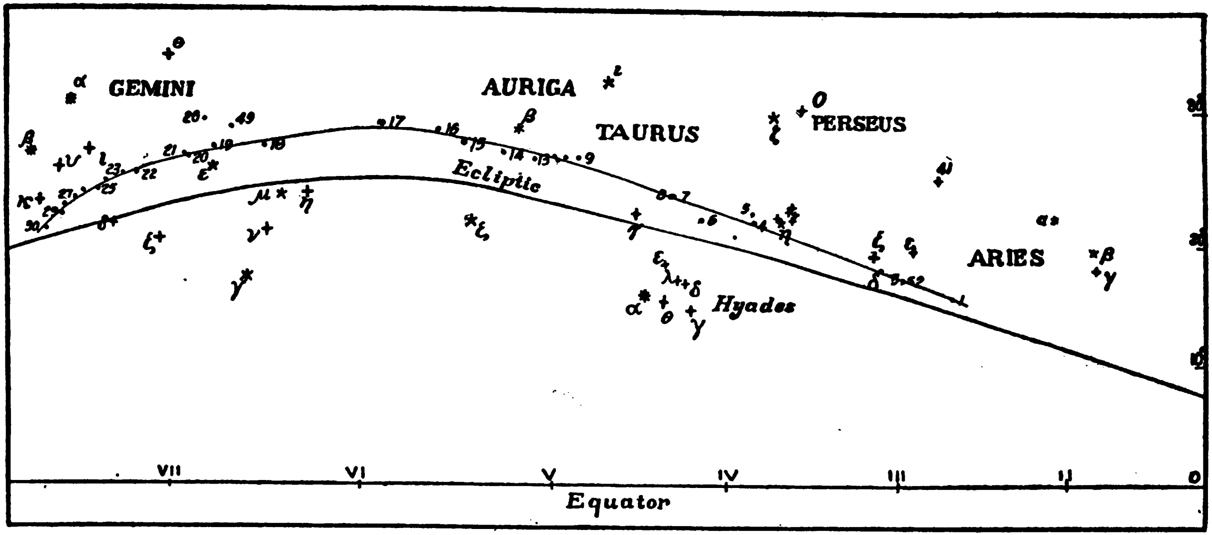

FIG. 14.—Path of Venus Among the Stars.

declination motion was in opposite directions, first north 10°, then south 4°, reckoning to the nearest degree. To fix the point farthest north, the planet's path is marked out as usual by passing a fine cord, stiff with wax, as symmetrically as possible with regard to the points plotted on the globe (§ 57). Examination then shows that the greatest declination of Venus is, +26°.5, but during two weeks, from April 26 to May 10, there is no measurable change in declination, though meanwhile right ascension increases nearly an hour. This constancy of declination is, however, not surprising, as later it is found that its value, according to the Ephemeris varies, during the interval, less than 0°.4. And the best naked-eye observations are likely to be in error one or two-tenths of a degree, and globe checking is certainly less accurate.

The globe makes it practicable to find approximately the greatest eastern elongation of Venus, that is, its greatest angular distance from the sun during the synodic period involved. Any measure of the distance between the positions fixed for the sun and planet on the same date, gives the angle of elongation, and to find when it is greatest, it is only necessary to make a number of measures. The value obtained April 13, is 45°.3, before that, less, between this date and April 26, there is no perceptible change, but after that it grows less again. The angle given in the Ephemeris for greatest elongation is 45°.6 on April 26; but the uncertainty about the date from the globe plot does not signify poor observing nor any unusual inaccuracy in the globe. Reference to the Ephemeris shows that between April 13 and 26, the planet gains in right ascension $9^m.2$ on the sun but loses 2° 27′ in declination. Therefore, since the relative change in coördinates is small, nearly equal and in opposite directions, the angular distance between the two bodies cannot change largely. Calculation gives an increase of half a degree between the dates mentioned (Byrd, § 72).

84. Planets, nebulae, and stars with small telescope.—In making the first observation of these objects with the telescope,

attention should center on simple definite points like those given in the working list below:

1. Examine Venus near inferior conjunction when it shows the crescent phase. Compare it as regards form, size, and color with the new moon seen directly, without magnifying power.

2. See whether the telescope affects the color of Mars, and whether it shows a disk for the planet.

3. Observe Jupiter twice in the same evening, and make, each time, a diagram showing the position of the satellites. Describe the belts if they are visible.

4. Look at Saturn and note whether or not the appearance of the rings is like that which Galileo obtained with his telescope.

5. Examine the nebulæ of Andromeda and Orion and see how they differ in size, form, and brightness.

6. Describe the appearance of three of the following star-clusters:

The Pleiades: Præsepe in Cancer; Coma Berenicis; H. VI; 33, 34, near η Persei; M. 13, between η and ζ Herculis.

While making observations, keep in mind points like these:

(1) Difference between opera-glass (§ 77) and telescopic views.
(2) Density and form of cluster, and size in terms of the field of view.
(3) Approximate number of stars by count or estimate.
(4) Tendency to cluster in any noticeable way.
(5) Range in magnitude of stars and contrasts in color.

7. Examine about half the double stars in the list below:

(1) ζ Ursæ Maj., *i. e.*, Mizar and Alcor.
(2) α Capricorni.
(3) ϵ Lyræ.
(4) β Lyræ.
(5) ν Draconis.
(6) δ Orionis.
(7) θ Orionis.
(8) β Cygni.
(9) 61 Cygni.
(10) ζ Piscium.
(11) θ Serpentis.
(12) ζ Ursæ Maj., *i. e.* Mizar.
(13) α Geminorum.
(14) γ Virginis.

8. Make a diagram of the telescopic field showing Mizar and Alcor, the neighboring eighth magnitude star, and the components of Mizar.

The first two stars of the list are very wide doubles, called sometimes naked-eye doubles, and the components of ϵ Lyræ, though nearer together, are still widely separated. Let the distance between the components of these three be estimated in terms of the field of view, and the brightness of the other two compared with Mizar and Alcor. For the closer doubles, Mizar itself serves well for a standard, both as regards the distance and the brightness of the two stars. In addition to the comparison of each double star with a given pair, taken as a standard, note the color and relative magnitude of the components of each pair.

85. General problem of time with transit instrument.—It is not a very difficult undertaking to find time from observations made with a transit instrument placed in the meridian, if a few astronomical formulæ are accepted without demonstration (§ 86). Were the instrument perfect and perfectly adjusted, a single perfect record of the transit of one star across one thread would give directly the time sought, that is the error of the sidereal clock; for it would be simply the difference between the record of the clock and the right ascension of the star (§ 49).

Since, however, these ideal conditions are never realized, at least four stars should be observed over as many as three threads; and account taken of the errors in level, azimuth, and collimation. The mean of the times on the different threads is, then, the time of observation, and according to Mayer's formula ("Comstock's Field Ast.," § 75, (149)), the transit of each star gives an equation of the form,

$$a - T = \Delta T + Aa + Bb + Cc,$$

where a is the right ascension of the star, T its sidereal time of transit, ΔT the approximate clock error, and the other three terms the corrections for the errors just mentioned. In these terms the capital letters, A, B, and C signify the factors that

are constant for a given star at a given place. Their values in terms of latitude and declination are,

$$A = \frac{\sin(\varphi - \delta)}{\cos\delta}, \qquad B = \frac{\cos(\varphi - \delta)}{\cos\delta}, \qquad C = \frac{1}{\cos\delta}.$$

At any place where a transit instrument is in routine use for determining time, it is customary to compute these factors for different values of declination, and arrange them in tables, called *A B C* Tables.

The small letters signify instrumental errors. The error in azimuth, a, is the angular deviation of the rotation axis from due west, plus when the deviation is south, minus when north. The error in level, b, is the angular deviation of the rotation axis from the plane of the horizon, plus when the west end of the axis is high, minus when low. The error of collimation, c, is the angular deviation of the standard sight-line from the collimation axis. Both of these lines pass through the so-called "optical center" of the object-glass, but the axis of collimation is that which is perpendicular to the rotation axis, and the sight-line is defined as that which passes through the standard thread, real or imaginary, the former being usually the middle thread and the latter the mean of the threads. The sign of c is plus when the sight-line, from thread to objective, intersects the celestial sphere to the east of the collimation axis. It follows, therefore, that when the rotation axis is reversed, *i. e.*, turned end for end, the sign of c is changed. Hence, to obtain well balanced data, it is usual to observe an even number of stars, half with one position of the rotation axis and half with the other.

In actually recording the transits, it is by no means necessary to employ a sidereal time-piece. With home-made appliances, a watch set to standard time is often more convenient (§ 88).

The instrument used in obtaining the set of star transits given in the following section is like that described in § 10, and illustrated in Fig. 15 which is the same as Fig. 1. The diameter of the object-glass is 1.5 inches and the magnifying power 30 (§ 81). Instead of spider threads, fine, black silk threads are inserted

in the negative eye-piece. They present the appearance of heavy bars, do not require much light, and so make it possible to observe sixth magnitude stars, though the fifth is a preferable limit. The rotation axis has neither clamp nor setting circle.

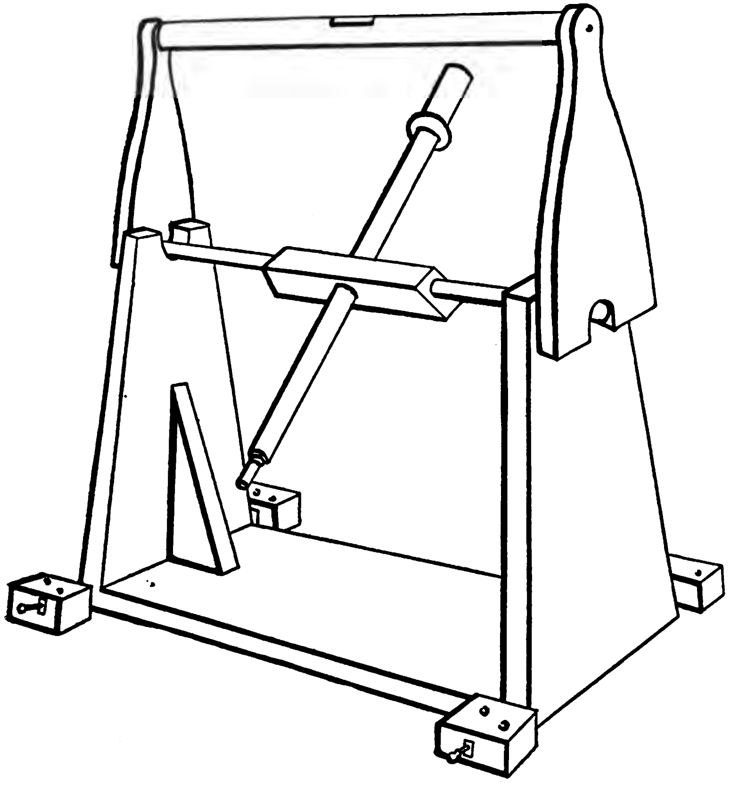

FIG. 15.—Home-Made Transit Instrument.

The two positions of the axis may be designated by the numbers I and II, according as the end marked I or II is to the east. The telescope is held in any desired position by means of a counterpoise which is merely a narrow bag of bird-shot fitted tightly around the tube near the lower end of the dew cap. To

facilitate "settings," that is, the pointing at individual stars, eight or ten so-called declination lines are drawn along the rotation axis at either end. Each one was made to coincide with the heavy reference line on the inner face of the east wye, when a carefully identified star was in the center of the field of view, and its declination marked on the line. Hence, it follows that to bring a star into the field, it is only necessary, a little before its time of transit, to turn the telescope until the declination line of the star coincides with the line of reference just mentioned. For stars that have no declination lines, settings are made by interpolating. Changes in level that shift the reference line interfere somewhat with this method; but, as with any transit instrument, the star's magnitude and time of meridian transit aid in identifying it.

A numerical evaluation of the level error is impracticable, but the rotation axis is carefully adjusted by placing, under one end or the other, pieces of thin pasteboard made to fit the wyes, and testing with the striding level. A difference in one thickness of paper is easily detected, and it is not difficult to reduce the level error practically to zero, considering the standard of accuracy required with an instrument of this character. In making the reduction of observations, therefore, the term Bb is dropped from Mayer's formula.

A set of eight stars, taken half before and half after reversal, usually gives a fair determination of the collimation error, but that for azimuth is more troublesome, as it is difficult to reverse the instrument without changing its value.

86. Time with home-made transit instrument.—The only problem to be considered here, and that rather beyond the scope of the book, is to find the error of a common watch with the simplest appliances.

Observation.—W. V., Lawrence, Kan., Saturday, Oct. 30, 1909. Two sets of eight stars each are observed with the instrument described in the preceding section. On its base, well lighted by a lantern near it, an Elgin watch is placed in a cushioned box. The observer, following the star across the field,

looks down as it disappears behind each of the three bars, and notes time, a crude method of recording which naturally introduces rather large accidental errors. On this date, the moon being not far from full, gives all needed illumination for the field of view (§ 10).

The working list for this observation consists of a number of stars and their coördinates taken from the Ephemeris. All are included that are available during several hours, as far as they meet the necessary conditions of brightness and position.

The principal data for the first set of stars are given in the following table:

TABLE VII.—TIME SET, SATURDAY, OCT. 30, 1909, W. V., LAWRENCE, KAN.

STARS, POS. I.	DECL.	EQUATIONS.	ΔT's.
11 Cephei	+70° 54′	$-1^m\ 50^s.5 = \Delta T - 1.6\,a - 3.1\,c$	$-1^m\ 35^s.3$
α Aquarii	− 0 46	$-1\ 41.8 = \Delta T + 0.6\,a - 1.0\,c$	−1 38 .4
γ Aquarii	− 1 51	$-1\ 38.6 = \Delta T + 0.7\,a - 1.0\,c$	−1 35 .4
π Aquarii	+ 0 55	$-1\ 37.8 = \Delta T + 0.6\,a - 1.0\,c$	−1 34 .4
STARS, POS. II.			
η Aquarii	− 0 35	$-1\ 28.2 = \Delta T + 0.6\,a + 1.0\,c$	−1 33 .2
ζ Pegasi	+10 22	$-1\ 28.8 = \Delta T + 0.5\,a + 1.0\,c$	−1 33 .7
ι Cephei	+65 44	$-1\ 26.3 = \Delta T - 1.1\,a + 2.4\,c$	−1 34 .9
α Pegasi	+14 43	$-1\ 31.3 = \Delta T + 0.4\,a + 1.0\,c$	−1 36 .1

To obtain the equations in the third column of the table, numerical values are substituted in Mayer's formula, the term bB having been dropped, as already explained (§ 85). First, the star's right ascension, which is its sidereal time of transit (§ 49), is reduced to local mean time (Byrd, § 53), and then to standard time by applying a correction of $21^m\ 12^s$, the best known value of the longitude from the standard meridian (§ 87, Ex. 2, *b*). The difference between this theoretical time of transit, and that observed with the watch keeping standard time gives its approximate error, $a - T$. This constitutes the first member of the equation, and the minus sign before it indicates that the watch is fast (§ 36).

The second member contains the corrections that are required in finding the true watch error, and here A and C, the coefficients of a and c have been replaced by their values taken from A B C Tables. There too the signs are given, and C is found positive for all the stars of the set, but it is known that the collimation error, c has opposite signs for positions I and II (§ 85), and so, for one position or the other, Cc must be negative. When the solution has been completed, a positive c simply means that the signs of Cc, *i. e.*, of c were entered correctly at first, a negative value, that the signs taken must be reversed in giving the collimation error for the particular position of the instrument.

After the eight equations have been formed in this manner, the problem is to derive the watch error ΔT, and a and c, the instrumental errors. The discussion of the theory of reduction cannot be taken up here, but it must be noted that the unknown quantities are not to be treated exactly like x, y, and z in the common algebraic equation. The solution may be carried out as follows,* where the equation marked p is that derived from the north star or polar, and that marked m is obtained by taking the mean of the three equations, based upon the time stars:

$$\begin{aligned}
-1^{m}\,50^{s}.5 &= \Delta T - 1.6\,a - 3.1\,c \quad (p)\\
-1\ \ 39\,.4 &= \Delta T + 0.6\,a - 1.0\,c \quad (m)\\
-0\ \ 11\,.1 &= \qquad +2.2\,a + 2.1\,c \quad (n = m - p)\\
-0\ \ \ 5\,.0 &= \qquad +\ \ a + 1.0\,c \quad (q = \tfrac{n}{2.2})\\
-1\ \ 42\,.4 &= \Delta T \qquad\qquad - 1.6\,c \quad (m_1 = m \text{ with } q \text{ substituted})
\end{aligned}$$

For Pos. II the equations obtained in like manner are:

$$\begin{aligned}
-1^{m}\,26^{s}.3 &= \Delta T - 1.1\,a + 2.4\,c \quad (p')\\
-1\ \ 29.\,4 &= \Delta T + 0.5\,a + 1.0\,c \quad (m')\\
-0\ \ \ 3.\,1 &= \qquad +1.6\,a - 1.4\,c \quad (n')\\
-0\ \ \ 1.\,9 &= \qquad +\ \ a - 0.9\,c \quad (q')\\
-1\ \ 28.\,4 &= \Delta T \qquad\qquad + 1.4\,c \quad (m_1')
\end{aligned}$$

*The writer learned about this particular form of reduction from Dr. T. H. Safford, for many years Professor of Astronomy at William's College, and, as far as known, it was original with him.

To find the unknown quantities, solve first for c. Its value derived from q and q', the equations containing a and c, is $3^s.6$, from the equations containing ΔT and c, $4^s.7$, making the mean value, $4^s.2$, negative for Pos. I. By substituting this value for c in q and q', and taking the mean, a is found to be $+1^s.4$; and a like substitution in m_1, and m_1' gives the mean ΔT, -1^m $35^s.0$ at $8^h\ 10^m$, the mean of the times of the different star transits. The values of ΔT for each star, given in the last column of the time-set table, are obtained by substituting c and a in the eight equations. As already noted, the method of recording probably affected especially these individual errors, but the fact that their mean for Pos. I is larger than for Pos. II indicates the need of a further correction for collimation. Refinements of this kind, however, belong rather to instruments of precision than to the rude, ten-dollar make-shift which is here considered.

The second set of eight stars is reduced like the first, and gives the value of ΔT, $-1^m\ 32^s.0$ at $10^h\ 9^m$, making the mean of the two errors, $-1^m\ 33^s.5$ at $9^h\ 10^m$, the mean of the times of the two sets. A little later at $9^h\ 30^m$, the watch is compared by telephone with the clock of A. Marks, a Lawrence jeweler, who courteously took pains to have standard time correct to the nearest second. Several signals were given and the final result made the watch fast, $1^m\ 34^s.5$. While this error is not to be regarded as absolutely correct at the time of comparison, and a change may have taken place in the watch during 20^m, it is probable, all things considered, that the determination of time from the 16 stars was correct within a second.

87. Latitude and longitude without observation.—These geographical coördinates may be obtained from maps, more or less accurately, depending on the scale of the map and its degree of accuracy.

EXERCISE 1.—Given the latitude and longitude of the State University, Lawrence, Kan., $+38°\ 57'.2$ and $6^h\ 20^m\ 58^s$ W. (Appendix); required to find from a map the latitude and longitude of Ft. Riley, Kan.

The map employed is "King's Grammar School Geography," used in the schools of the state (1910), and having a scale of 26 miles to the inch. With strips of rectangular paper, I make three mesaures of the distance by which Ft. Riley is north of Lawrence and the same number of its distance west. The means of the linear distances, reduced to degree measure for this part of the map, makes the fort $5'.5$ north of Lawrence and $5^m\ 25^s$ west. So, according to this determination, its latitude is, $+39°\ 2'.7$ and longitude $6^h\ 26^m\ 23^s$ W. (C. J. W.)

The values given by the Commandant of the Post are, latitude, $+39°\ 3'.8$ and longitude, $6^h\ 27^m\ 9^s$ W.

If the distances involved are small, the required coördinates may be found by counting "sections" when practicable, for a section is exactly a square mile in those parts of the country where land is laid out regularly in sections and ranges.

Exercise 2.—Taking the latitude and longitude of the State University given in Exercise 1, find by the aid of section lines the latitude and longitude of Wide View.

(a) By reckoning the sections in the farms between the university and the given place, the latter is located three miles west, and three-quarters of a mile south of the university station. The problem, then, is to reduce miles to degrees. Now, a degree of longitude in linear measure decreases rapidly as distances from the equator increase, but a degree of latitude increases slightly. For this place, as the distance considered is small, it is sufficiently accurate to take 69 miles equal to one degree of latitude, and hence three-fourths of a mile equals $39''$. This subtracted from the latitude of the university, $+38°\ 57'\ 15''$ makes that of Wide View, $+38°\ 56'.6$. In the locality considered, the value of one degree of longitude used in the survey of public lands, carried far enough for this exercise, is 53.87 miles. Therefore, three miles equals $0°.056$ or $13^s.4$, making the longitude of Wide View, $6^h\ 21^m\ 11^s.4$.

(b) In this exercise, more accurate results are derived from a critical sectional map of the vicinity of Lawrence, which is available, since it includes both the university buildings and the

house at Wide View. Careful measures with rectangular paper place this house 0.75 miles south of the university station, a value agreeing with that found above (Byrd, § 5), but the distance west is 3.18 miles, which according to the method employed in *a*, equals $0^\circ.059$ or $14^s.16$.

It follows that the required coördinates, obtained for Wide View, by subtracting $39''$ from the latitude of the university and adding 14^s to its longitude are,

Latitude, $+38^\circ\ 56'.6$ and longitude, $6^h\ 21^m\ 12^s$ W.

While this method gives no warrant for claiming that tenths of seconds are known, the value found for the longitude of Wide View is doubtless correct to the nearest half second of time.

88. Longitude from time determinations.—To deal intelligently with the actual determination of longitude, it is essential to have a clear idea of just what longitude is. Young defines it as "the angle at the pole of the earth between the standard meridian and the meridian passing through the place" (Young, Art. 61). This angle is measured by the arc intercepted on the equator, and that, in turn by the time required for a star or the mean sun (Byrd, § 37) to pass over the arc.

Since the meridian of Greenwich is commonly taken as the standard or zero meridian, all points for example, where the sun marks noon an hour later than at Greenwich are said to be in longitude one hour west of Greenwich. The problem of finding the longitude of any place, therefore, consists in obtaining the local time at the place, and then, for that instant, ascertaining the corresponding Greenwich time. The latter, however, is not often one of the stations directly employed, as the older observatories in any country, whose longitude from Greenwich is accurately known, serve as standards of reference.

For example, let *A* be on the zero meridian, *B*, a station whose longitude from *A* is known, and *C*, the place whose longitude is required. The local time at *C* compared with that at *B* gives the difference in longitude between *C* and *B*, and *C*'s longitude from *A* is then found by simple addition or sub-

traction, according as B is west or east of A; for west longitudes are reckoned plus and east, minus.

EXERCISE.—From the determination of local time at Wide View, Lawrence, Kan., required to find approximately the longitude of the station.

The error of the Elgin watch employed was ascertained on three dates, Sept. 11, 25, and Oct. 30, the day of the week in each case being Saturday, so that comparison could be made in the evening with jeweler's time in town.

To illustrate the method of procedure, the October observations are taken. They are the same that have been discussed in § 86, but here the treatment is different, for in the present problem, longitude instead of being given, as before, is the quantity to be determined. Reference to the original notes for this date shows that longitude was then really unknown, but that the Ephemeris time of transit was reduced by a provisional longitude, $21^m\ 8^s$, to approximate standard time, and that the watch showed on its face the same kind of time.

While this is the convenient way to use a watch in observing, in the subsequent reductions, it is desirable to deal only with local time. This is readily effected, for the times to be considered are simply the two times of star transit, that derived from the Ephemeris and that obtained by observation. The first is expressed in local time by the mere omission of the correction for longitude, in making the reduction from sidereal time; and the local time of transit is found without tampering with the hands of the watch, for it matters not at all whether they are set back a certain number of minutes and seconds before observations are taken, or whether afterward, this interval is subtracted from the recorded time of transit.

Therefore, to find the first member, $a - T$ of each fundamental equation, take, for example, 11 Cephei of the first set, Oct. 30. Its local time of transit from the right ascension of the Ephemeris is $7^h\ 5^m\ 45^s.5$ (§ 49), its standard time of transit, actually recorded is $7^h\ 28^m\ 48^s$, but the corresponding local time, obtained by subtracting the correction used for longitude, $21^m\ 8^s$, is

$7^h\,7^m\,40^s$, and the difference between these two times, *i. e.*, $-1^m\,54^s.5$ gives the required, $a-T$. In the same way $a-T$ is derived for the other stars, and the solution of the two sets of observations carried out from this point as in § 86 makes the error of local mean time, $-1^m\,39^s.0$ at $7^h\,49^m$, and, $-1^m\,36^s.0$ at $9^h\,48^m$, or if means are taken, the watch error is, $-1^m\,37^s.5$ at $8^h\,48^m$.

This determination of local mean time constitutes the first and most laborious part of the work demanded in finding longitude. Theoretically considered, the next step is to compare the time-piece of Wide View with a clock at some station where longitude has been accurately determined, for the difference in the longitude between two stations is the difference in their local times. So far, no mention has been made of a second station, and indeed no one in particular is required. The one thing necessary is to make a comparison with a clock which keeps correctly the time of a meridian at a known distance from Greenwich. But this is precisely what is done by any clock keeping correct standard time; for standard time is the local time of the standard meridian (§ 22), and all standard meridians are separated from Greenwich by a known number of hours.

In the present exercise local time at Wide View was compared with the local time of the 90th meridian, *i. e.*, with standard time in the time section of the place. The actual comparison was effected between the watch used at Wide View and the clock of a Lawrence jeweler set to standard, that is 90th meridian time. Instead of telegraphing as in a regular longitude "campaign," the telephone was employed, though, of course, several signals were given.

The mean of the corresponding readings with watch error is:

Local time at Wide View.	Error of Elgin Watch at $8^h\,48^m$.	Local time of 90th Meridian.
$9^h\,9^m\,56^s.5$	$-1^m\,37^s.5$	$9^h\,29^m\,30^s$

Since it is impracticable to ascertain the watch error for the exact minute of comparison, it seems more reasonable to assume

that it is constant between $8^h\ 48^m$ and $9^h\ 10^m$ than to apply a correction for rate, as is usual with the clock of an observatory. The corrected local time at Wide View is, then, $9^h\ 9^m\ 56^s.5 - 1^m\ 37^s.5$ or $9^h\ 8^m\ 19^s.0$, and this subtracted from the 90th meridian time, $9^h\ 29^m\ 30^s$ gives $21^m\ 11^s$ as the difference in longitude between the two meridians. And finally, since the meridian, with which comparison is made, is 90° west of Greenwich, the longitude of Wide View, according to this observation, is $6^h\ 21^m\ 11^s$ W.

The principal data for the three nights, when observations were taken for longitude, are given in the following table, where W. V. and W. V. T. stand, respectively, for Wide View and Wide View time.

TABLE VIII.—LONGITUDE OF WIDE VIEW.

Date of Obs.	No. of Stars.	Watch Error fr. Obs. at W. V.	Comparison of Time-pieces. W. V. Watch.	Comparison of Time-pieces. Jeweler's Clock.	90th M. T. − W. V. T.
1909.					
Sept. 11^d $9^h.7$	8	$+0^m\ 50^s.5$	$8^h\ 53^m\ 1^s.5$	$9^h\ 15^m\ 0^s.0$	$+21^m 8^s.0$
Sept. 25 7 .5	8	−1 35 .9			
Sept. 25 13 .0	8	−1 37 .8			
10 .2	16	−1 36 .8	9 20 24 .0	9 40 0.0	12 .8
Oct. 30 7 .8	8	−1 39 .0			
Oct. 30 9 .8	8	−1 36 .0			
8 .8	16	−1 37. 5	9 9 56 .5	9 29 30.0	11 .0

The values in the final column are, of course, obtained as above by correcting the watch time for its error, and then taking the difference between the corrected local time at Wide View, and the 90th-meridian time of the jeweler's clock. The mean of the three nights taken directly is $21^m\ 10^s.6$. If, as seems rea-

sonable, each night is weighted according to the number of stars observed (Byrd, § 4) the mean obtained is, $21^m\ 11^s.1$, and this makes the whole longitude of Wide View, west of Greenwich, $6^h\ 21^m\ 11^s$, a value, a second smaller than that derived in *b* of the preceding section.

Another determination of the longitude of this station has been made from the occultation of five stars by the moon; and though the work involved is incomparably greater, the final result, $6^h\ 21^m\ 15^s$, is less accurate than that above, based on the determination of local time. The latter is certainly the method to be preferred by amateurs, depending upon simple appliances.

APPENDIX.

Latitudes and Longitudes of Places for Illustrative Exercises:

Place.	Latitude.	Longitude.	Authority
Ann Arbor, Mich.	+42° 16′.8	+5h 34m 55s	American Ephemeris
Arequipa, Peru	−16 24	+4 45 30	American Ephemeris
Baltimore, Md.	+39 17 .5	+5 6 27	U. S. Geological Survey
Boston, Mass.	+42 21 .5	+4 44 15	American Navigator
Charlottesville, Va.	+38 2 .0	+5 14 5	American Ephemeris
Cleveland, Ohio	+41 30 .1	+5 26 49	U. S. Geological Survey
Columbia, Mo.	+38 56 .9	+6 9 18	American Ephemeris
Denver, Colo.	+39 40 .6	+6 59 48	American Ephemeris
Ft. Riley, Kan.	+39 3 .8	+6 27 9	Commandant at Ft. Riley
Galveston, Tex.	+29 18 .3	+6 19 10	American Navigator
Greenwich, Eng.	+51 28 .6	0 0 0	American Ephemeris
Hartford, Conn.	+41 45 .6	+4 50 42	U. S. Geological Survey
Key West, Fla.	+24 33 .4	+5 27 14	American Navigator
Lawrence, Kan.	+38 57 .2	+6 20 58	U. S. Geological Survey
Montreal, Canada	+45 30 .3	+4 54 19	American Ephemeris
Nashville, Tenn.	+36 8 .9	+5 47 12	American Ephemeris
New Orleans, La.	+29 57 .8	+6 0 14	American Navigator
New York, N. Y.	+40 48 .6	+4 55 50	American Ephemeris
New York, N.Y., N. Col.	+40 46	+4 55 51	U. S. Geographical Survey.
Northfield, Minn.	+44 27 .7	+6 12 36	American Ephemeris
Northampton, Mass.	+42 19 .0	+4 50 33	American Ephemeris
Omaha, Neb.	+41 15 .7	+6 23 43	Encyclopædia Britannica
Oxford, Miss.	+34 22 .2	+5 58 7	American Ephemeris
Philadelphia, Pa.	+39 57 .1	+5 0 38	American Ephemeris
Portland, Me.	+43 37 .4	+4 40 50	U. S. Geological Survey
Portland, Ore.	+45 32	+8 10 9	Smithsonian Meteor'l Tables
Raleigh, N. C.	+35 47	+5 15 2	Encyclopædia Britannica
Salt Lake City, Utah	+40 46 .1	+7 27 35	U. S. Geological Survey
San Francisco, Calif.	+37 47 .5	+8 9 43	American Ephemeris
Santa Fé, N. M.	+35 41 .1	+7 4.1	Loomis Pract. Astronomy
Savannah, Ga.	+32 4 .9	+5 24 22	American Navigator
South Hadley, Mass.	+42 15 .3	+4 50 20	American Ephemeris
Washington, D. C.	+38 55 .2	+5 8 16	American Ephemeris
Wellesley, Mass.	+42 17 .7	+4 45 18	American Ephemeris

INDEX.

(All references are to *sections*, not to *pages*.)